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SEA-WATER SYSTEMS FOR EXPERIMENTAL AQUARIUMS

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UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF SPORT FISHERIES AND WILDLIFE
RESEARCH REPORT 63

RESEARCH REPORTS

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A Collection of Papers

Edited by
John R. Clark and
Roberta L. Clark

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RESEARCH REPORT 63

UNITED STATES DEPARTMENT OF THE INTERIOR
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FISH AND WILDLIFE SERVICE
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NOTE

The Bureau of Sport Fisheries and Wildlife does not endorse particular products or equipment. References to trade names and manufacturers of equipment in the accounts by various laboratories of their experiences in setting up salt-water aquariums have been retained for identification. The Bureau neither recommends nor disapproves the products referred to.

SEA-WATER SYSTEMS FOR EXPERIMENTAL AQUARIUMS

This volume was created to provide a source of information on design, construction, and operation of experimental aquarium facilities. The idea developed out of our own frustrated search for published material on sea-water supply systems when we were planning facilities for the new Sandy Hook Marine Laboratory. We found that we had to spend many weeks visiting laboratories and many months corresponding with aquarists to obtain the information we needed. It became clear, as a result of this, that nearly everyone who has built a sea-water system has experienced similar difficulties.

The solution to this problem suggested by J. L. McHugh of the U.S. Bureau of Commercial Fisheries was that we prepare a volume on sea-water systems from our visits and correspondence. We decided rather to sponsor a compilation of papers contributed by the aquarists themselves. In soliciting papers, we asked contributors to describe their experiences in solving problems encountered in designing, constructing, and maintaining systems, rather than give detailed and comprehensive accounts of complete sea-water systems. Our letter of invitation to potential contributors stated:

> We visualize such a publication as addressed primarily to the biologist and secondarily to the engineer and containing accounts of personal experiences illustrated by simple sketches of general layout or special features. Annotated descriptions of recirculating systems, holding tanks, rearing ponds, or other facilities would be pertinent. Of great value would be descriptions of methods for combating such problems as fouling, siltation, equipment failure, and toxicity of system components. Discussions of such factors as selection of pumps and advantages of continuous versus interrupted supply would be appropriate also. Discussions of past or present shortcomings of systems and possible remedies would also be helpful to others planning experimental facilities. Contributions would not have to be lengthy to be of value. I believe the readers of such a volume would be interested in simple systems as well as those of more elaborate design.

We attempted to embrace as great a variety of experience in sea-water aquarium problems as possible. That some success was achieved in this aim is evident from the scope of the contributed papers. Geographic coverage extends from the tropics to temperate latitudes and from the mid-Pacific Ocean to the eastern Atlantic Ocean. Environmental coverage extends from estuarine to open coastal emplacements. System coverage extends from small recirculating tanks to continuous-supply systems of hundreds of gallons per minute. Nearly every problem which could arise with sea-water systems is explored in one paper or another.

In attempting broad scope, we have included papers ranging from the philosophical to the very practical. Thus, all concerned, from experimental biologists to maintenance personnel, should find this volume useful. The comprehensive index was included to enhance its value as a reference work and as a manual for design, construction, operation, and maintenance of all types of experimental sea-water supply systems.

John R. Clark, *Marine Biologist.*
Roberta L. Clark, *Editorial Assistant.*

SOME PRINCIPLES AND PRACTICES OF WATER MANAGEMENT FOR MARINE AQUARIUMS

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Abstract.—Instability of sea water and its organic constituents, when confined in aquariums or circulatory systems, and the characteristic inability of marine organisms to adjust to changes in their environment, combine to make the keeping of marine life in captivity a difficult procedure. The maintenance of sea water in suitable condition depends upon a chemically inert water system, a low ratio of animal life to volume of water, the control of bacteria, and the elimination of metabolic waste products. Methods used to accomplish this include aeration, filtration, storage in the dark, and treatment with alkalizers, ultraviolet light, and antibiotics.

Despite a tradition that goes back to the ancient Romans and a lively, uninterrupted history of more than a century, the keeping of marine animals in captivity remains more of an art than a science. The most valuable attribute an experimentally minded marine biologist can have is a wet thumb. Of course, the more he is able to apply precise, reproducible techniques to the maintenance of his subjects, the greater are his chances of success, but there will inevitably remain some intangibles, indescribable and unpredictable, that he, as scientist, can only attribute to the complexity of the subject he is dealing with.

Central to the problem of keeping marine animals alive in aquariums is the maintenance of sea water in such confined bodies. In his classic elucidation of the coordinate roles played by the fitness of the environment and the fitness of the individual in the evolution of life, Henderson (1913) points out that in no other habitable place on the earth are so many conditions so stable and so enduring as in the ocean. This eon-embracing stability of the sea as an environment of life is the fundamental cause of the difficulties that marine laboratories, public aquariums, and home aquarists alike have in keeping marine fishes and invertebrates. Because these animals evolved in a world that has remained practically constant in temperature, osmotic pressure, alkalinity, and chemical composition, they have developed few mechanisms to isolate themselves from these environmental factors and little tolerance for change. In captivity, they perforce must be provided with an environment that at least approaches in stability their natural one. But once sea water has been removed from the ocean, it begins to change and to lose some of its capacity to support delicate marine life. This is directly and indirectly the result of its no longer being part of a body of water that is to all intents and purposes infinitely large. The best that any marine aquarium practices seem to be able to do is merely to slow down the rate of this deterioration.

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MATERIALS SUITABLE FOR SEA-WATER SYSTEMS

Any discussion of water as an environment, artificial as well as natural, ought at least to mention the attributes that intimately connect this unique substance with life, namely its great specific heat, latent heats of fusion and evaporation, and thermal conductivity, its high surface tension and dielectric constant, its transparency, and its tremendous solvent power combined with chemical stability. These characteristics were first penetratingly analyzed by Henderson (1913), and they have been reviewed by Sverdrup, Johnson, and Fleming (1942). Of them, only water's close approach to being the universal solvent presents any special problems in aquarium management.

Because of water's ability to dissolve a wide variety of toxic substances and because of the extreme sensitivity of most aquatic animals to them, the only certain way to keep water suitable for most marine life is to use chemically inert materials throughout the water system. Copper is a good example of a problem material. This heavy metal is acutely toxic to fresh-water fish in concentrations of a few parts per hundred million, but in hard alkaline waters its toxicity is considerably reduced (Doudoroff and Katz, 1953). In sea water, as might therefore be expected, copper is somewhat less toxic, and at the New York Aquarium and the John G. Shedd Aquarium, prophylactic doses of 0.20 to 0.25 p.p.m. (parts per million) are considered safe for the great majority of marine fishes (Carleton Ray, personal communication; Braker, 1961). At the Steinhart Aquarium, however, a number of marine fishes have been found to be sensitive to concentrations of less than 0.20 p.p.m. (Herald et al., 1962).

Invertebrates are much more sensitive; for example, sea-urchin larvae were strongly affected by 0.03 p.p.m. of copper (Wilson and Armstrong, 1961). Surprisingly little metallic copper need be exposed to sea water to produce a dangerous concentration of dissolved copper. Braker (1961) placed two U.S. pennies in a system containing 6 gallons of sea water with 1 gallon per hour flowing over the copper coins. He found a concentration of 0.1 p.p.m. of copper in the ambient sea water at the end of 12 hours, and 0.58 p.p.m. at the end of 48. (At this rate, it would take more than 5 years for the coins to dissolve.) We have received several reports that fresh sea water flowing through a single copper, brass, or bronze fixture can pick up enough copper to kill larvae. One reason for the acute sensitivity of fishes and aquatic invertebrates to a heavy metal under these conditions is that they act as biological accumulators, removing the metal from solution and retaining it.

Few determinations of the toxicity of substances in sea water have been made, but materials toxic in fresh water are usually also toxic in sea water, although somewhat less so. Exceptions are known. Boëtius (1960) found that although mercuric chloride is less toxic to small fish in sea water than it is in fresh, phenylmercuric acetate is more toxic in sea water. Certain aquarium cements, whose performance in fresh water is satisfactory, break down in salt water and release substances that kill fish. In general, all metals should be avoided, even those like lead and stainless steel that are sometimes considered safe. Wood and other questionable materials may be covered with several coats of a good grade of black asphaltum varnish, but this protective coating will not last indefinitely and requires periodic checking. Cement is inert, but only after it has been "cured," a process that may take months. Chemically ideal for sea-water systems is hard rubber, also called

vulcanite and ebonite, the use of which was first recommended by Michael Faraday in 1857 (Lloyd, 1871). In recent years, a number of plastics have also proved satisfactory. Not all plastics are safe to use, however. In fact, if there is any doubt about the suitability of a material, it ought to be rigorously tested, by the animals themselves, as recommended and described by MacGinitie (1947).

NATURAL CONSTITUENTS OF SEA WATER

Overlying the differences between sea water in nature and in confinement is the basic similarity of its composition the world over. The ratios between the nine ions which constitute more than 99 percent of its dissolved salts are virtually constant (Sverdrup, Johnson, and Fleming, 1942; Harvey, 1955). This is a fortunate circumstance that permits a great deal of uniformity in approach and procedure by aquarists and experimentalists as well as oceanographers. On the other hand, at least 52 elements have been found in natural sea water, and this complexity has led to some irrational ideas about its chemical composition, particularly in connection with its duplication in the laboratory as artificial sea water. A fundamental difficulty is that conventional chemical notation cannot represent a mixture of many anions, cations, and molecules, all in dynamic equilibrium. There is perhaps no more striking illustration of this and its relation to life in the sea than the observation that a volume of sea water allowed to evaporate to dryness and then reconstituted with the proper amount of distilled water will not support the variety of marine life it originally would.

Moreover, as found in nature, sea water is not only an inorganic complex. An ever-increasing number and variety of organic substances are being found in it. Although there is very little organic matter in sea water quantitatively speaking, evidence is accumulating that the little there is exerts an important influence on marine life (Collier, 1953; Lucas, 1955; Nigrelli, 1958). Among the various types of organic substances that have been found in sea water are enzymes, vitamins, pigments, amino acids, antibiotics, and toxins, most of them presumably produced as external metabolites or ectocrines by plants and animals in the sea. The role that such minute constituents of sea water can play in maintaining marine life in captivity has been determined for only a few microorganisms, and their fate, when subjected to the changes that "captive" sea water undergoes, is unknown. Nevertheless, their existence is noted here because of the good possibility that some of them may be important in the culturing of larval forms and macroscopic invertebrates.

Whatever may be their bases, the differences between various natural sea waters can be extraordinarily subtle, as the decade of painstaking work by Wilson and Armstrong has shown. Faced with similar mysteries, aquarists have attributed a sort of *élan vital* to sea water and called it "living"—for instance, when they have observed that artificial sea water had to be inoculated with some of the natural stuff before most invertebrates and some fishes would live in it. Vitalism is not the answer, of course, but there are vital constituents of sea water that are still unrecognized.

CHANGES OCCURRING IN SEA WATER REMOVED FROM THE SEA

Within 30 minutes after a volume of sea water has been taken from the sea, detectable chemical changes have occurred in it (Collier and Marvin, 1953). Biotic ac-

tivity is responsible for this, the forerunner of a series of profound changes that are brought about in stored sea water by bacteria. Although the sea contains a widely distributed microscopic fauna and flora consisting of protozoans, algae, fungi, yeasts, and bacteria, only bacteria have as yet been found to be important in sea water maintained in vessels or water systems (ZoBell, 1946, 1959; Harvey, 1955). When fresh, filtered sea water is stored, there is a tremendous increase in the number of bacteria, a maximum population of from 2 million to 100 million per cc. being attained in 3 to 6 days at room temperature (ZoBell and Anderson, 1936). In about 2 weeks the initial growth phase is over, and the population then fluctuates from a few thousand to more than 100,000 per cc. At the same time, the number of species of bacteria is drastically reduced to less than half a dozen. Sea water stored for 4 years at 2° to 6° C. still contained more than 200,000 bacteria per cc. (ZoBell and Anderson, 1936), while that stored at room temperature became practically sterile in 6 months (MacGinitie, personal communication).

During the period of the precipitous growth and decline in number of bacteria and for some time thereafter, stored sea water is lethal to the more delicate creatures reared in marine laboratories (MacGinitie, 1947). Because of similar difficulties, aquarists using natural sea water in small aquariums (up to about 100 gallons) subscribe to the procedure of storing the water in glass in the dark for 6 weeks before use. The lethal effect appears to result from the presence of bacterial metabolites, since aeration is not supposed to relieve the condition. In contrast, public aquariums have never reported any difficulties with fresh sea water, perhaps because of the much greater volumes of water, more effective filtration, and lack of delicate forms in their establishments.

The control of bacteria must be one of the principal objectives in the management of salt-water systems and aquariums, but so little is known about the forms that occur in these artificial habitats that any approach is largely empirical. Although sea water has well-recognized bactericidal effects, it also provides an excellent medium for some bacteria, and when enriched with organic matter, may contain billions per cc. These microorganisms can reduce the amount of dissolved oxygen. They can also produce asphyxiating amounts of carbon dioxide and in this way, as well as others, may dangerously lower the pH. Under anaerobic conditions, they produce methane and hydrogen sulphide, the latter of which is known to be strongly toxic to fish (Doudoroff and Katz, 1950). Quite possibly they produce metabolites that are inimical to higher forms. Although this has never been demonstrated, Harvey (1925) found that sea water in which a worm had putrified or to which enough peptone had been added to make it become cloudy was toxic to a species of copepod for some days, even after it had been filtered through a Berkfeldt candle several times and also well aerated.

A *sine qua non* of bacterial control in confined bodies of sea water is cleanliness, achieved by avoiding overfeeding and overcrowding and by practicing systematic but not stereotyped cleaning procedures. In addition, four methods of reducing the number of bacteria have been used, viz., filtration, storage in the dark, ultraviolet treatment, and addition of antibiotics. The efficacy of filtration and storage had been well known long before Stowell and Clancey (1927) found, at the London Aquarium, that storage in the dark for 28 days eliminated "66 per cent. of the ordinary bacteria and 97 per cent. of the so-called 'blood-heat' organisms and bacteria of the human intestinal type,"

and Lackey (1956) determined that passage through the filters at Marine Studios (Marineland) generally removed more than half of the circulating bacteria. Herald et al. (1962) found that exposure to ultraviolet reduced demonstrable bacterial populations of 1,200 to 2,000 per cc. to practically zero. Marshall and Orr (1958) successfully used chloromycetin and streptomycin to prevent the bacterial multiplication that occurs when fresh sea water is put into aquariums, but there were indications that antibiotics may sometimes harm invertebrates exposed to them.

The importance of microorganisms, especially bacteria, to the state of the water in marine aquariums can scarcely be overemphasized, and not until we have a better understanding of bacterial activities can we hope to develop a truly rational technique of taking care of it. The fundamental difference between the behavior of small standing fresh-water aquariums and those containing sea water lies with their microbiology. The real "balance" of the former consists in the relatively stable condition of its microbial population, even in the presence of quite large amounts of organic material. The basis for this phenomenon is not definitely known. Breder (1931) has suggested that it may be partly the development of buffering capacity by the water and the appearance of bacteriophage, while studies of Dr. Seymour Hutner have indicated that the development of a dominant population of predatory protozoans is largely responsible. The situation in fresh water may well be exceptional, but the reasons for its absence in sea water would nevertheless be of interest. For example, bacteriophages have been found in the ocean (Spencer, 1960), but they do not seem to have been looked for in marine aquariums or other artificial environments.

CHANGES OCCURRING IN SEA WATER AFTER LONG USE

The outstanding changes occurring in sea water that has been kept in circulatory systems for months or years are two: a permanent lowering of the pH and an accumulation of nitrates. After 20 years of use, an analysis of the sea water in the New York Aquarium revealed that the nitrate content had increased more than 250-fold and that the pH had dropped below neutrality (Townsend, 1928). Similar data, involving similar or shorter periods of time, have been reported for the London Aquarium (Stowell, 1926a; Brown, 1929; Oliver, 1957), the Amsterdam Aquarium (Honig, 1934; Sunier, 1951), and the Ueno Aquarium (Saeki, 1958).

In nature, the pH of sea water seldom exceeds 8.4 or drops below 7.5 (Sverdrup, Johnson, and Fleming, 1942). It is regulated by a series of chemical equilibria involving carbon dioxide, carbonic acid, sodium bicarbonate, and sodium carbonate which forms a buffer mechanism and makes possible the addition of relatively large amounts of acid or alkali before the pH is appreciably altered (Harvey, 1928, 1955). If enough acid is added, all the excess base (alkali reserve) will be destroyed, but this occurs at a pH of 5.5, a far stronger acidity than the vast majority of marine fishes and invertebrates can endure. There has been disagreement as to the exact source of the acidity brought about by the metabolism of fish, in addition to that caused by the carbon dioxide they produce, but it is agreed that oxidation is the ultimate fate of practically all the excretions of fish— which is, of course, an acid-producing process.

Three methods of maintaining the pH in marine circulations have been used. At the Plymouth Aquarium, freshly slaked

lime ($Ca(OH)_2$) is periodically added to the reservoir (Brown, 1929; Atkins, 1931; Wilson, 1952, 1960). At the New York Aquarium, sodium bicarbonate ($NaHCO_3$) was added continuously to the circulating water (Breder and Howley, 1931), and modifications of this procedure have been used by other aquariums including the John G. Shedd Aquarium and the London Aquarium. At the Amsterdam, London, Ueno, and New York Aquariums, quantities of some form of calcium carbonate ($CaCO_3$) such as bivalve shells, marble chips, coral sand, or calcite, are kept in contact with the circulating water (Sunier, 1951; Oliver, 1957; Saeki, 1958). The relative merits of treatment with slaked lime or sodium bicarbonate were briefly argued by Breder and Howley (1931), Atkins (1931), Breder and Smith (1932), and Cooper (1932). One noteworthy aspect of this is the great importance that Breder (1934) attributed to the calcium ion in keeping captive marine fishes.

Although there are differences of opinion whether ammonia is the characteristic excretory product of aquatic organisms (Smith, 1953), it is agreed that this substance is at least one of the principal waste products of fish and aquatic invertebrates. It is also the main nitrogenous substance resulting from the bacterial decomposition of plant and animal tissues under both aerobic and anaerobic conditions in sea water (ZoBell, 1959). Since ammonia is highly toxic to fish in fresh waters, particularly alkaline ones (Doudoroff and Katz, 1950), and there is every reason to believe that it is comparably toxic in sea water, the fate of this metabolite is of considerable concern to the marine aquarist. Some ammonia passes into the atmosphere; the remainder, which is undoubtedly the bulk of it, is oxidized by bacteria to nitrites and nitrates. Large numbers of these bacteria are found in aquarium filters, but some also live on the walls of the tanks (Saeki, 1958). In a quantitative experiment concerning the nitrogenous substances in closed sea-water circulations, Saeki (1958) found that about 25 percent of the decrease in ammonia resulted from oxidation in the filter by its *Schmutzdecke*. Storage of aquarium water in the dark also reduces its ammonia content (Stowell, 1926b). The latter may be the result of direct chemical oxidation as well as biotic activity (Harvey, 1955; Vaccaro, 1962). There are bacteria that reduce nitrates and nitrites to nitrogen and others that reduce nitrates to nitrites, but what significant part, if any, they play in the nitrogen cycle of aquariums is unknown.

In fresh water, nitrates are hardly more toxic to fish than chlorides (Trama, 1954), and no adverse effects on marine species have ever been reported. According to Oliver (1957), however, nitrate can interfere with the respiratory processes of some animals, in particular marine invertebrates. Effects of nitrite do not ever seem to have been described. Oliver (1957) has pointed out that there is no chemical way of removing nitrate, and to accomplish this some adaptation of the denitrifying activities of bacteria appears to offer the most promise. Indeed, Honig (1934) was able practically to eliminate nitrite and nitrate in an experimental marine system by encouraging the multiplication of denitrifying bacteria, but Sunier (1951) reported that the practical application of her method presented difficulties. In a 6,600-gallon sea-water system at the Wuppertal zoological gardens, the combination of filtration by a pressure filter charged with activated carbon and a specially encouraged growth of marine algae kept nitrite and nitrate concentrations within the range of natural sea water (Seiffge, 1941).

The reduction of nitrate and nitrite to ammonia and the formation of ammonia from bacterial decomposition of pro-

teinaceous substances causes an increase in the pH of sea water, while bacterial oxidation of ammonia to nitrite or nitrate causes a decrease (ZoBell, 1959). These relationships require consideration, for Saeki (1958) has reported that a low pH inhibits the oxidation of ammonia in aquariums.

DISSOLVED RESPIRATORY GASES

Sea water can dissolve about 20 percent less oxygen than fresh water; at 20° C., for example, oxygen-saturated sea water (salinity 36 parts per thousand) contains 7.12 p.p.m. of that gas, as compared with 8.84 for distilled water (Truesdale, Downing, and Lowden, 1955). A survey of the literature has shown that the minimum oxygen requirements of marine fishes range from 3.3 to 0.1 p.p.m. At the London and Plymouth aquariums, Brown (1929) found that the sea-water systems were 60 to 90 percent saturated with oxygen. No temperatures are given, but at 20° C., this would correspond to at least 4 p.p.m., and at 30° C., to 3.6 p.p.m., which may be considered adequate for the majority of fishes.

The carbon dioxide content of sea water influences the respiration of fish by reducing the amount of oxygen carried by their red blood corpuscles (Fry, 1957). This is also a pH effect, and it would therefore be expected that sea water whose pH was low—whether from an accumulation of carbon dioxide or a loss of alkali reserve—would inflict respiratory stress on various fishes. Although general aquarium experience bears this out, no experiments to demonstrate the phenomenon have ever been reported. A pH of 7.8 or more appears to be safe for all fishes, while one of 7.0, or even 6.8, is adequate for some of them (Oliver, 1957). One important characteristic of carbon dioxide and its passage between the sea and the atmosphere is that the process takes place relatively slowly, and even with artificial aeration may require several hours (Harvey, 1928, 1955).

Marine fishes that are exposed to sea water supersaturated with air frequently develop gas-bubble disease in which bubbles, mostly of nitrogen, appear under the skin, especially on the fins, and within various vital organs, causing exophthalmia, loss of equilibrium, and death. The supersaturation generally results from a leaky pump or pipeline which permits air to enter and mix with water that is put under pressure, or from a sudden, relatively great increase in water temperature. Marsh and Gorham (1905) first described the disease and its cause in detail, and their account was based on its occurrence in fishes living in a sea-water circulatory system. Since then, all investigations appear to have been carried out on fresh-water species (Harvey and Smith, 1961). Dr. Ross F. Nigrelli, Pathologist of the New York Aquarium, has suggested that denitrifying bacteria may be a source of nitrogen that causes gas-bubble disease.

For the aquarist or experimentalist with a physicochemical background, the papers by Downing and Truesdale (1955, 1956) and Haney (1954) provide basic and theoretical data on the aeration of aquariums.

MARINE CIRCULATORY SYSTEMS

From the preceding account, there can be little doubt of the complexity of interrelations between captive marine macro- and micro-organisms and the sea water

in which they live (see fig. 1). Early aquarists considered their aquariums and water systems to be microcosms whose elements behave in the same way as they do in the whole earth's grand economy (e.g., Lankester, 1856; Mather, 1880), and this

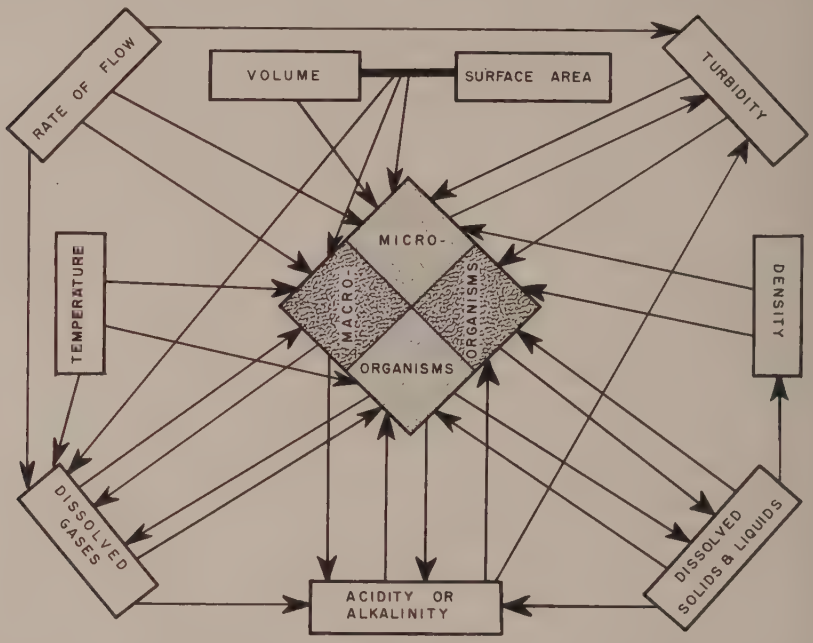

FIGURE 1.—Diagram of the complex interactions of macroorganisms and microorganisms and environment in a marine aquarium or sea-water system. Arrows point from the agent or influencing factor to the item changed or influenced.

attractive but erroneous idea has persisted for many years (see Stowell, 1926a). As a consequence, the early aquarists who discovered such vital techniques as circulating the sea water, storing it in the dark, and aerating it, attributed their usefulness to quite incorrect reasons (Lloyd, 1871; Newman, 1873). Standing on the shoulders of these pioneers, we now recognize many significant differences between the bionomics of aquarium systems and the sea.

The need for constant treatment of sea water in order to keep it satisfactory for marine life is apparent. At the very least, sea water must be aerated continuously, but unless it is to be replaced often and unless the ratio of volume of water to volume of animals living in it is extremely large, circulation, filtration, and storage in some sort of reservoir are also necessary. In a typical circulatory system, the water flows from tank (exhibition, holding, or experimental) to filter, to reservoir, and back to tank (see fig. 2). Aerators are frequently located between each of these units and the next. The pump is placed after the reservoir because it is least likely to become clogged with animals, sand, or solid wastes at this spot. A gravity tank greatly facilitates the regulation of water flow into the animals' tanks and lessens the chance of introducing water supersaturated with air.

Systems in which the water is recirculated, being used over and over, are called

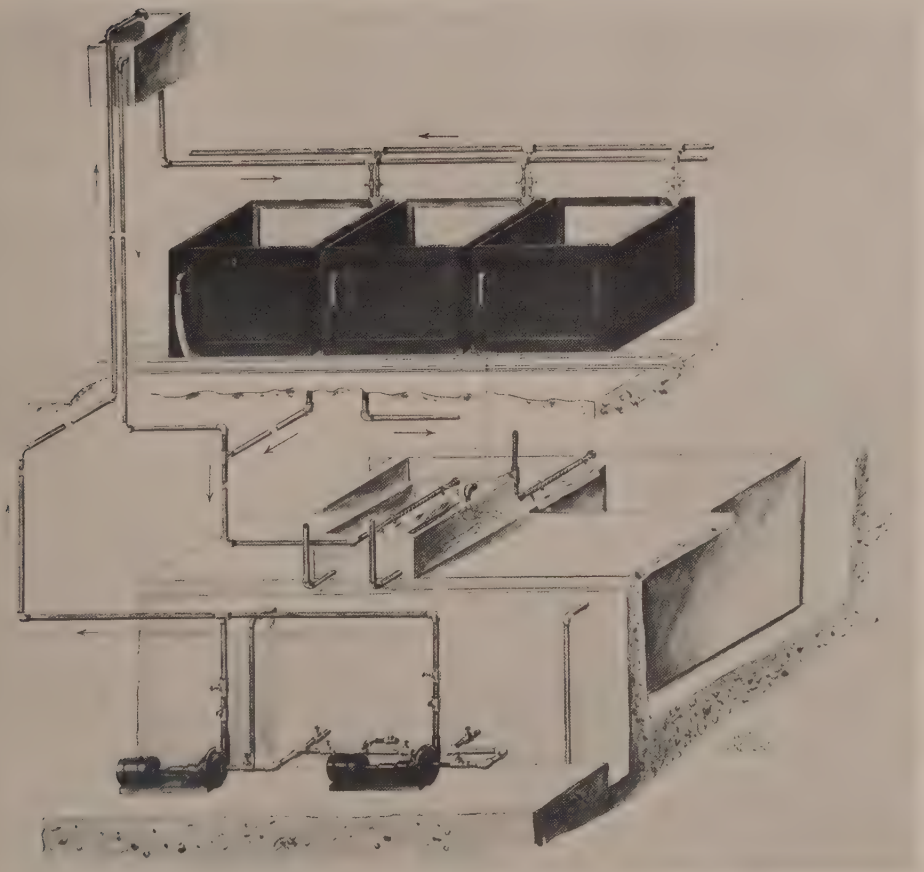

FIGURE 2.—Typical closed sea-water circulatory system. The water flows as follows: Holding tank (black) to return trough and pipeline, to manifold aerator, to filter, to manifold aerator, to reservoir, to pump, to supply riser, to gravity tank, to supply pipeline, to holding tank. Note that all service units, except the gravity tank, are in duplicate and that valves are arranged to provide complete flexibility—that is, all possible combinations of units. The holding tanks are connected to two supply pipelines, and a length of flexible hose from each overflow makes it possible to use either return trough.

"closed." A typical "open" sea-water system has been described by Hinton (1958). In this, the water is used once and then discarded. The tanks of such a system should be connected in parallel to the water source, not in series, so that each tank receives the same kind of water, and disease cannot be spread through the water from tank to tank. Both Hinton (1958) and MacGinitie (1947) point out that the storage tank, which provides an emergency supply of water if the pumps fail and also acts as a settling tank, should not contain more than a 36-hour supply and that a 24-hour supply is usually sufficient.

In order to prevent the spread of disease and facilitate water treatment, each tank should have its own circulatory system with an individual pump, filter, and reservoir, but the expense of initial installa-

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tion and of maintenance may preclude this ideal arrangement, especially if large tanks are involved. When the units have been small enough (less than 1,000 gallons) that they could be provided adequate circulations by means of air lifts, individual sea-water circulatory systems have been set up in public aquariums, for example, at Wuppertal (Wiedemann, 1943) and Bern (Hediger, 1944). Ingenious modifications of filters and aquariums making them more suitable for individual circulations have been described by Wiedemann, by Chin (1959), and by Kelley and Moreno (1961).

In some sea-water systems, there is no filter; instead the water is allowed to pass slowly through a large settling tank or reservoir. Herald et al. (1962) have compared this type with the one using filtration, and they indicate that the latter carries a greater proportion of animals, viz., about 50 gallons of sea water per pound of living animals as compared with about 450 gallons for a system depending on sedimentation alone. Wilson (1952, 1960) has described a typical filterless system. In his later paper, he stresses the importance of having a reservoir that is correctly designed, and he provides the details of a successful one now in use at the Plymouth Aquarium. One advantage of sedimentation over filtration is that filter-feeding invertebrates do better in unfiltered water (Wilson, 1952).

Filtering tests that were made on beds consisting of uniform-sized silica sand by William E. Kelley of the Cleveland Aquarium (unpublished report) and of a graded series of quartz or quartzlike filtrants by Herald et al. (1962) showed that practically all of the filtering was accomplished in the top few inches of the bed. Conventional deep filters would therefore appear not to be necessary in sea-water systems. Saeki (1958), however, has determined the amount of sand that will provide space for the bacteria necessary to oxidize the waste products of a fish, and he states that as a minimum the filtrant should weigh 30 times as much as the fish. Evidently volume as well as surface should be considered in calculating filter requirements. An example of a shallow-bed filter that uses a uniformly sized filtrant is shown in figure 3.

Hinton (1958) has discussed the problem of an optimum rate of flow in a sea-water circulation and concludes that it is difficult to have too much sea water. The

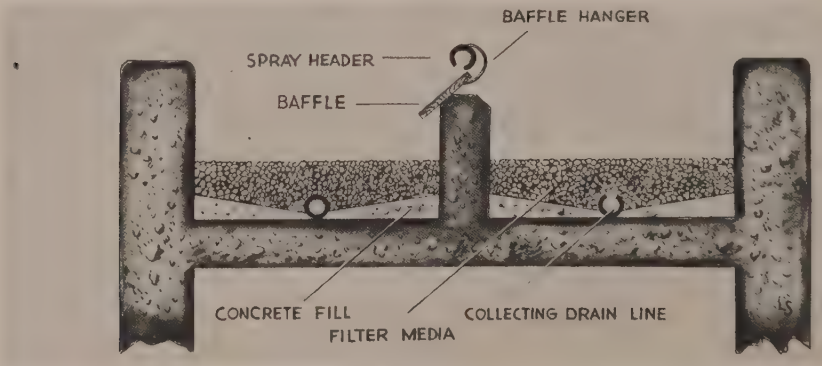

FIGURE 3.—Cross section of shallow-bed filter seen in figure 2. The spray header acts as a manifold aerator, and the baffle can be reversed to direct the water into the opposite filter chamber. Backwashing water is introduced into the collecting drain line through its elevated open end (seen in figure 2).

water in the tanks of the aquarium at the Scripps Institution of Oceanography is changed once every 3 to 5 hours, and this has proved satisfactory. At the Plymouth Aquarium, however, a turnover of slightly more than four times a day was barely adequate (Wilson, 1960). At the Amsterdam Aquarium, an entirely different situation prevails, with the water in each tank being replaced on an average of only 1½ times a day (Sunier, 1951). We believe that for most laboratories and aquariums, an ideal rate would be 20 to 24 changes of water a day (see Addendum).

A cardinal, though unproven, principle of sea-water management is that the greater the volume, the slower its rate of deterioration. General aquarium experience, without any doubt, abundantly supports the corollary principle that the ratio of volume of sea water to volume of animals kept in it should be as large as possible. Wilson (1952) has reported an informal experiment that was dictated by World War II at the Plymouth Aquarium: "During the war when most of our big tanks were broken and empty, the inhabitants of those which remained did noticeably better, and delicate organisms survived longer than they did before the war, or do now, and sometimes even bred." The greatest ratio ever maintained in a large sea-water circulation seems to be that in the Amsterdam Aquarium, where the tanks containing the marine animals comprise but one sixth of the total volume of the system. One way of lengthening the useful life of a volume of sea water is to divide it into two equal parts and alternatively "rest" half of the water in a dark reservoir, usually for a month or 6 weeks (Stowell and Clancey, 1927; Wilson, 1952, 1960).

ADDENDUM

On the basis of the work of Saeki (1958) and experiments recently performed at the Cleveland Aquarium, Kelley (1963) has described the parameters of an ideal sea-water circulatory system. The relation of volume of water to weight of animals maintained in it is 100 gallons to 1 pound. The water circulates completely once every hour and passes through the filter at a rate of 1 gallon per square foot per minute. The filtrant consists of 2- to 5-mm. grains of silica gravel (75 percent) and calcareous gravel (25 percent) and there is 1 cubic foot of it for each pound of animal.

LITERATURE CITED

Atkins, W. R. G.
1931. Note on the condition of the water in a marine aquarium. Journal of the Marine Biological Association of the United Kingdom, vol. 17, No. 2, pp. 479–481.

Boëtius, Jan.
1960. Lethal action of mercuric chloride and phenylmercuric acetate on fishes. Meddelelser fra Danmarks Fiskeri- og Havundersøgelser, n.s., vol. 3, No. 4, pp. 93–115.

Braker, William P.
1961. Controlling salt water parasites. The Aquarium (Norristown, Pa.), vol. 30, No. 1, pp. 12–15.

Breder, Charles M., Jr.
1931. On the organic equilibria in aquaria. Copeia, 1931, No. 2, July 20, p. 66. Abstract of paper.
1934. Ecology of an oceanic fresh-water lake, Andros Island, Bahamas, with special reference to its fishes. Zoologica (New York), vol. 18, No. 3, pp. 57–88.

Breder, Charles M. Jr., and Thomas H. Howley.
1931. The chemical control of closed circulating systems of sea water in aquaria for tropical marine fishes. Zoologica (New York), vol. 9, No. 11, pp. 403–442.

Breder, Charles M., Jr., and Homer W. Smith.
1932. On the use of sodium bicarbonate and calcium in the rectification of sea-water in aquaria. Journal of the Marine Biological Association of the United Kingdom, vol. 18, No. 1, pp. 199–200.

Brown, Eleanor M.
1929. Notes on the hydrogen ion concentration, excess base, and carbon-dioxide pres-

sure of marine aquarium waters. Proceedings of the Zoological Society of London, 1929, No. 44, pp. 601–613.

CHIN, EDWARD.

1959. An inexpensive re-circulating sea-water system. Progressive Fish-Culturist, vol. 21, No. 2, pp. 91–93.

COLLIER, ALBERT W.

1953. The significance of organic compounds in sea water. Transactions of the Eighteenth North American Wildlife Conference pp. 463–472.

COLLIER, ALBERT W., and KENNETH T. MARVIN.

1953. Stabilization of the phosphate ratio of sea water by freezing. U.S. Fish and Wildlife Service, Fishery Bulletin, No. 79, vol. 54, pp. 69–76.

COOPER, L. H. N.

1932. On the effect of long continued additions of lime to aquarium sea-water. Journal of the Marine Biological Association of the United Kingdom, vol. 18, No. 1, pp. 201–202.

DOUDOROFF, PETER, and MAX KATZ.

1950. Critical review of literature on the toxicity of industrial wastes and their components to fish. I. Alkalies, acids, and inorganic gases. Sewage and Industrial Wastes, vol. 22, No. 11, pp. 1432–1458.

1953. Critical review of literature on the toxicity of industrial wastes and their components to fish. II. The metals, as salts. Sewage and Industrial Wastes, vol. 25, No. 7, pp. 802–839.

DOWNING, A. L., and G. A. TRUESDALE.

1955. Some factors affecting the rate of solution of oxygen in water. Journal of Applied Chemistry, vol. 5, pp. 570–581.

1956. Aeration in aquaria. Zoologica (New York), vol. 41, No. 16, pp. 129–143.

FRY, F. E. J.

1957. The aquatic respiration of fish. The physiology of fishes, edited by Margaret E. Brown, vol. I, pp. 1–63 Academic Press, New York.

HANEY, PAUL D.

1954. Theoretical principles of aeration. Journal of the American Water Works Association, vol. 46, No. 4, pp. 353–376.

HARVEY, H. H., and S. B. SMITH.

1961. Supersaturation of the water supply and occurrence of gas bubble disease at Cultus Lake trout hatchery. Canadian Fish Culturist, No. 30, pp. 39–47.

HARVEY, HILDEBRANDE WOLFE.

1925. Oxidation in sea water. Journal of the Marine Biological Association of the United Kingdom, vol. 13, No. 4, pp. 953–969.

1928. Biological chemistry and physics of sea water. Cambridge University Press. x+194 pp.

1955. The chemistry and fertility of sea waters. Cambridge University Press. viii+224 pp.

HEDIGER, HEINI.

1944. Erfahrungen aus dem aquarium des Tierparkes Dählhölzli in Bern. Schweizerische Fischerei-Zeitung, 1944, Nos. 8/10. 22 pp.

HENDERSON, LAWRENCE J.

1913. The fitness of the environment. Macmillan, New York. (Republished in 1958 by Beacon Press, Boston. xxiv+317 pp.)

HERALD, EARL S., ROBERT P. DEMPSTER, CLYDE WOLTERS, and MARJORIE L. HUNT.

1962. Filtration and ultraviolet sterilization of seawater in large closed, and semi-closed aquarium systems. Communications I^{er} Congrès International d'Aquariologie, vol. B, pp. 49–61.

HINTON, SAM.

1958. The T. Wayland Vaughan Aquarium-Museum. University of California, Scripps Institution of Oceanography, La Jolla, Calif. 42 pp.

HONIG, C.

1934. Nitrates in aquarium water. Journal of the Marine Biological Association of the United Kingdom, vol. 19, No. 2, pp. 723–725.

KELLEY, WILLIAM E.

1963. Ideal configurations for a semi-closed circulating aquarium system. Program, 50th anniversary meeting, American Society of Ichthyologists and Herpetologists, p. 43. Abstract of paper.

KELLEY, WILLIAM E., and DANIEL H. MORENO.

1961. A filtering system for individual tanks. Bulletin of Aquatic Biology, vol. 2, No. 21. pp. 117–118.

LACKEY, ELSIE WATTIE.

1956. Some visibility problems in large aquaria, II. A bacteriological study of the sea water used in Marineland. Quarterly Journal of the Florida Academy of Sciences, vol. 19, No. 4, pp. 267–273.

LANKESTER, EDWIN.

1856. The Aquavivarium, fresh and marine. Robert Hardwicke, London. 71 pp.

LLOYD, WILLIAM ALFORD.

1871. The Crystal Palace Aquarium. Nature, vol. 4, pp. 469–473.

LUCAS, C. E.

1955. External metabolites in the sea. Deep-Sea Research, vol. 3, Supplement, pp. 139–148.

MacGinitie, G. E.
1947. Sea water systems at marine laboratories. Science, vol. 106, No. 2747, pp. 171–173.

Marsh, M. C., and F. P. Gorham.
1905. The gas disease in fishes. U.S. Bureau of Fisheries, Report of the U.S. Commissioner of Fisheries for 1904, Appendix, pp. 343–376.

Marshall, S. M., and A. P. Orr.
1958. Some uses of antibiotics in physiological experiments in sea water. Journal of Marine Research, vol. 17, pp. 341–346.

Mather, Frederick.
1880. Management of public aquaria. Transactions of the American Fisheries Society (Transactions of the American Fish Cultural Association), 1879, pp. 46–50.

Newman, Edward.
1873. Official handbook to the marine aquarium of the Crystal Palace Aquarium Company (Limited). By W. A. Lloyd, Superintendent of the Aquarium. Fifth edition, revised and enlarged. 1873. Review. The Zoologist; a Popular Miscellany of Natural History, 2 ser., vol. 8, pp. 3661–3676, 3701–3711, 3741–3759.

Nigrelli, Ross F.
1958. Dutchman's baccy juice or growth-promoting and growth-inhibiting substances of marine origin. Transactions of the New York Academy of Sciences, 2 ser., vol. 20, No. 3, pp. 248–262.

Oliver, James H.
1957. The chemical composition of the sea water in the aquarium. Proceedings of the Zoological Society of London, vol. 129, No. 1, pp. 137–145.

Saeki, Aritsune.
1958. Studies on fish culture in the aquarium of closed-circulating system; Its fundamental theory and standard plan. Bulletin of the Japanese Society of Scientific Fisheries, vol. 23, No. 11, pp. 684–695. (In Japanese with English abstract.)

Seiffge, W.
1941. Ein Beitrag zur Pflege des Seewassers. Der Zoologische Garten, n.s., vol. 13, Nos. 3/4, pp. 297–300.

Smith, Homer W.
1953. From fish to philospher. Little, Brown and Co., Boston. xv + 264 pp.

Spencer, R.
1960. Indigenous marine bacteriophages. Journal of Bacteriology, vol. 79, No. 4, p. 614.

Stowell, Flaxney P.
1926a. Physical and chemical conditions in the sea-water of the Zoological Society's aquarium—a comparison with the water of the open sea. Proceedings of the Zoological Society of London, 1925, No. 45, pp. 1241–1258.
1926b. The purification of sea-water by storage. Proceedings of the Zoological Society of London, 1926, No. 11, pp. 245–255.

Stowell, Flaxney P., and Vernon J. Clancey.
1927. Microscopical and bacteriological investigation of the water in the Society's aquarium. Proceedings of the Zoological Society of London, 1927, No. 18, pp. 295–306.

Sunier, A. L. J.
1951. The circulation and chemistry of the sea water in the Amsterdam Aquarium. Minutes of the meeting of the International Union of Directors of Zoological Gardens, held in Amsterdam, 1951.

Sverdrup, H. U., Martin W. Johnson, and Richard H. Fleming.
1942. The Oceans; their physics, chemistry, and general biology. Prentice-Hall, New York. 1087 pp.

Townsend, Charles Haskins.
1928. The public aquarium; its construction, equipment, and management. U.S. Bureau of Fisheries, Document 1045, Report of the U.S. Commissioner of Fisheries for 1928 (Appendix VII), pp. 249–337.

Trama, Francesco B.
1954. The acute toxicity of some common salts of sodium, potassium and calcium to the common bluegill (*Lepomis macrochirus* Rafinesque). Proceedings of the Academy of Natural Sciences of Philadelphia, vol. 106, pp. 185–205.

Truesdale, G. A., A. L. Downing, and G. F. Lowden.
1955. The solubility of oxygen in pure water and sea-water. Journal of Applied Chemistry, vol. 5, pp. 53–62.

Vaccaro, R. F.
1962. The oxidation of ammonia in sea water. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 27, No. 1, pp. 3–14.

Wiedemann, Eduard.
1943. Zum technischen Ausbau von Meeresaquarien. Der Zoologische Garten, n.s., vol. 15, No. 3, pp. 126–131.

Wilson, Douglas P.
1952. The aquarium and sea-water circulation system at the Plymouth laboratory. Journal of the Marine Biological Association

of the United Kingdom, vol. 31, No. 1, pp. 193–212.

1960. The new aquarium and new sea-water circulation systems at the Plymouth laboratory. Journal of the Marine Biological Association of the United Kingdom, vol. 39, No. 2, pp. 391–412.

Wilson, Douglas P., and F. A. J. Armstrong.
1961. Biological differences between sea waters: experiments in 1960. Journal of the Marine Biological Association of the United Kingdom, vol. 41, No. 3, pp. 663–681.

ZoBell, Claude E.
1946. Marine microbiology. Chronica Botanica Co., Waltham, Mass. xv+240 pp.

1959. Introduction to marine microbiology. New Zealand Department of Scientific and Industrial Research Information Series, No. 22, pp. 7–23.

ZoBell, Claude E., and D. Quentin Anderson.
1936. Observations on the multiplication of bacteria in different volumes of stored sea water and the influence of oxygen tension and solid surfaces. Biological Bulletin, vol. 71, No. 2, pp. 324–342.

A NEW FORMULA FOR ARTIFICIAL SEA WATER

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Abstract.—An artificial substitute for sea water is offered which has performed well in keeping both vertebrates and invertebrates at the Cleveland Aquarium. The formula is assembled and stored for convenient use as a 4-part preparation.

The use of artificial sea water is nearly as old as the keeping of marine aquariums. In 1854, Gosse, who was one of the principal popularizers of the home aquarium, both fresh-water and marine, described his experiences with simple mixtures of readily available chemicals that could be used when natural sea water proved too difficult to procure.

This was hardly a year after the opening of the world's first public aquarium in London. A few unsuccessful experiments with synthetic sea water were subsequently carried out in some of the early aquariums, but the first institution to use it with any success appears to have been the Berlin Aquarium, which opened to the public in 1869. The recipe was a simple one, involving only four salts, and, like the mixtures concocted by Gosse, it required an inoculation of seaweed or some similar living organisms to make it fit for higher forms of marine life (Hoffmann, 1884). If the great success claimed for this *Ersatzseewasser* was not at all exaggerated, it is difficult to find any reason why most aquariums did not evenutally adopt it. However, very few institutions have found artificial sea water to be a satisfactory substitute for the natural product, one noteworthy exception being another Berlin aquarium, which opened to the public in 1913, as described by Heinroth (1937).

Several different formulas for artificial sea water have been devised (table 1). The number of ingredients in them varies from 4 to 14, but the avowed purpose of them all was to provide as close a facsimile as possible to actual sea water.

THE BACKHAUS FORMULA

In December 1960, one of us (Kelley) visited the Exotarium of the zoological gardens of Frankfurt am Main, and while there was most favorably impressed with both the practical and the theoretical aspects of the synthetic sea water that had been prepared by Dr. Dieter Backhaus of that institution. Dr. Backhaus' approach to the problem had not been to try to imitate natural sea water, but to produce the artificial medium in which marine animals would thrive best, regardless of how closely it might or might not resemble the composition of sea water in nature. It was recognized that the synthetic mixture would have to resemble natural sea water at least in the rough proportions of its principal salts, but these were only taken as a general guide in the first formulations. The appearance and behavior of the many marine fishes and invertebrates on exhibition at the Exotarium attested to the soundness of the new approach, and Dr. Backhaus graciously made his formula available to us for further experiment.

We have modified the Backhaus formula for artificial sea water into a 4-step preparation as shown below (for preparing 100 gallons with specific gravity of 1.025):

PART I

$NaCl$	10.43	kg.	Technical grade.
$MgCl_2.6H_2O$	2.04	kg.	Do.
$MgSO_4.7H_2O$	2.62	kg.	Do.
KCl	277.8	g.	Do.
$NaHCO_3$	79.4	g.	Do.
$SrCl_2.6H_2O$	7.5	g.	Analytical reagent.
$Mn(SO_4)_2$	1.5	g.	Do.
$Na_2HPO_4.7H_2O$	1.25	g.	Do.
$LiCl$	.375	g.	Do.
$Na_2MoO_4.2H_2O$	.375	g.	Do.

PART II

$CaCl_2$	522	g.	Technical grade.

TRACE ELEMENT STOCK SOLUTIONS

Add 80 cc. each of solutions III and IV.

PART III

Calcium Gluconate	6.25	g.	U.S.P.
KI	.9	g.	Analytical reagent.
KBr	270.00	g.	Do.
$CuSO_4.5H_2O$	4.3	g.	Do.

Dissolve in 2 liters of distilled water.

PART IV

$Al_2(SO_4)_3$	4.5	g.	Analytical reagent.
$CoSO_4$	.5	g.	Feed grade.
$RbCl$	1.5	g.	Analytical reagent.
$ZnSO_4.7H_2O$	.96	g.	Do.

Dissolve in 2 liters of distilled water.

We have also altered a few of the proportions of its constituents:

1. The Backhaus formula includes slightly more than a millionth part of iron, which we have omitted because our Great Lakes tap water is relatively rich in this element.

2. The Backhaus formula calls for about one five-thousandth part of zinc sulfate and one fifty-thousandth part of copper sulfate. Fearing synergistic toxicity, we have reduced these to the amounts found in natural sea water.

3. We have eliminated the boric acid used by Dr. Backhaus to inhibit plant growth in amounts up to six ten-thousandth parts.

We have not found it necessary to use chemically pure (CP) substances throughout as did Dr. Backhaus.

Part I of the formula consists of its gross dry components, and these may be weighed and placed in a mixing tank. A hard stream of water directed into them will dissolve these chemicals. The container may then be filled almost to the level of the desired specific gravity.

Part II, which consists of the calcium chloride, is dissolved in hot water and added to the mix. Additional water may then be added to bring the mix to the correct specific gravity. Calcium chloride is mixed separately because, at the high concentrations of the gross components, it will react with the magnesium sulfate to form magnesium chloride and calcium sulfate, the latter of which will precipitate.

Parts III and IV, which are stock solutions of trace elements, may now be added to the mix. Liquid stock solutions of these are desirable because (1) the assembly of the parts is made more convenient, (2) some of the compounds providing trace elements must be dissolved by heat (calcium gluconate, cobalt sulfate, and aluminum sulfate), and (3) better quantitative accuracy may be achieved by weighing out relatively large amounts for the stock solutions. If chlorinated tap water has been used, the solution must be aerated for a day or two before adding parts III and IV, or the residual chlorine will displace the ionic bromine and iodine since the latter occupy a lower position in the electromotive series.

We have been able to maintain marine invertebrates indefinitely in this artificial sea water—something we have not been able to do with any other type.

A summary of references to various types of artificial sea water is given in the following listing:

Originator	*Reference*
Hermes, ca. 1880	Hoffmann (1884).
Schmalz, ca. 1913	Heinroth (1937), Needham et al. (1937), Hediger (1944).
Von Flack	Needham et al. (1937).
McClendon et al., 1917.	Needham et al. (1937), Sverdrup et al. (1942), Redfield (1948), Getchell (1953).
Brujewicz (in Subow, 1931).	Sverdrup et al. (1942), Redfield (1948), Getchell (1953).
Penn, A.B.K., 1934.	Needham et al. (1937).
Lyman and Fleming, 1940.	Sverdrup et al. (1942), Redfield (1948), Getchell (1953), Harvey (1955).
Dählhölzli	Hediger (1944).
U.S. Navy corrosion test. Aquarium.	Redfield (1948).
John G. Shedd Aquarium.	Getchell (1953).
Wilder, 1953	Pachtman (1956).

LITERATURE CITED

Getchell, John S.

1953. A study on the effect of recirculated natural and artificial sea water on the mortality of lobsters. Maine Department of Sea and Shore Fisheries, Research Bulletin 11. 23 pp.

Gosse, Philip H.

1854. The aquarium, an unveiling of the wonders of the deep sea. London. 278 pp.

Harvey, Hildebrande Wolfe.

1955. The chemistry and fertility of sea waters. Cambridge University Press. 224 pp.

Hediger, Heini.

1944. Erfahrungen aus dem Aquarium des Tierparkes Dählhölzli in Bern. Schweizerische Fischerei-Zeitung, 1944, Nos. 8/10. 22 pp.

Heinroth, O.

1937. Erfahrungen aus der Seewasser-abteilung des Berliner Aquariums. Der Zoologische Garten, n.s., vol. 9, No. 6, pp. 278–285.

Hoffmann, R. E.

1884. Artificial sea water for aquaria. U.S. Fish Commission, Bulletin, vol. 4, No. 30 (Oct. 1), pp. 465–467.

Lyman, John, and Richard H. Fleming.

1940. Composition of sea water. Journal of Marine Research, vol. 3, No. 2, pp. 134–146.

Needham, James G., Paul S. Galtsoff, Frank E. Lutz, and Paul S. Welch (Editors).

1937. Culture methods for invertebrate animals. Comstock Publishing Co., Ithaca, N.Y. 590 pp. Reprinted in 1959 by Dover Publications, New York.

Pachtman, E. A.

1956. Shipping and maintaining lobsters alive. U.S. Fish and Wildlife Service, Branch of Commercial Fisheries, TL 9. 7 pp.

Redfield, Alfred C.

1948. Characteristics of sea water. *In* The corrosion handbook, edited by H. H. Uhlig, pp. 1111–1122. John Wiley & Sons, New York.

Sverdrup, H. U., Martin W. Johnson, and Richard H. Fleming.

1942. The oceans; their physics, chemistry, and general biology. Prentice-Hall, New York. 1087 pp.

Wilder, D. G.

1953. Holding live lobsters in aerated artificial sea water. Fisheries Research Board of Canada, Atlantic Biological Station, Circular, General Series, No. 21. 4 pp.

NOTES FROM THE AQUARIUM OF THE MARINE LABORATORY, ABERDEEN

By H. J. Thomas

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Abstract.—The closed circulation system described comprises twin reservoir tanks, service tank, header tank, display tanks, and filter bed. Special features include construction in water-tightened concrete with vulcanite-lined cast-iron or alkathene tubing, reservoir tank capacity five times that of the display tanks, aerator pump which is water sealed, and the use of marble chips in the filter bed. The aquarium is furnished with several levels of temperature control to allow maintenance of the appropriate seasonal sea temperature. Isolation tanks are provided for experiments which might involve risks if undertaken in the main system.

The Marine Laboratory's aquarium is essentially a research tool, but the basic design, stocking, and temporary decoration of the tanks is adapted to afford as high a standard for display as is compatible with the primary function.

STRUCTURAL DATA

The basic layout follows the standard pattern for a closed-circulation sea-water aquarium (figs. 1 and 2). The relevant capacities and ratings of the main aquarium installations are as follows:

Volume of large display tanks (9 at 5 by 5 by 5 feet)	7,000 gallons.
Volume of small display tanks (8 at 3 by 2½ by 2½ feet)	800 gallons.
Volume of portable tanks (as required)	400 gallons.
Total volume of display tanks	8,000 gallons.
Volume of service tank	500 gallons.
Volume of header tank	350 gallons.
Reservoir/sedimentation twin tanks, each of capacity	40,000 gallons.
Main circulation pump rated capacity	4,000 gallons per hour.
Filter bed, combined total filter area	12 by 16 feet.
Refrigerator rated capacity	60,000 B.t.u.
Heater capacity	3 kilowatts.

Reinforced, water-tightened, sulphate-resisting, concrete units are poured in a single operation, thereby avoiding sutures with consequent corrosion of the reinforcing by sea water. In the reservoir tanks where single-operation pouring is difficult, the outer reinforced-concrete shell is lined with asphalt, and this in turn is supported by a brick layer internally faced with water-tightened concrete. The reservoir tanks are constructed with a sump to facilitate pumping out.

Display-tank walls are smoothed, and all corners are rounded.

One-inch-thick plate-glass fronts to the display tanks are, at their deepest, 4 feet 6 inches from the water surface. Glasses are bonded into position with Glasticon cement of the grade appropriate to the area of the bonding surface, which must be true, and to the depth of the tank.

The original sea-water piping is of vulcanite-lined cast iron. Extensions and replacements are undertaken using alkathene (Imperial Chemical Industries—I.C.I.—black polyethylene).

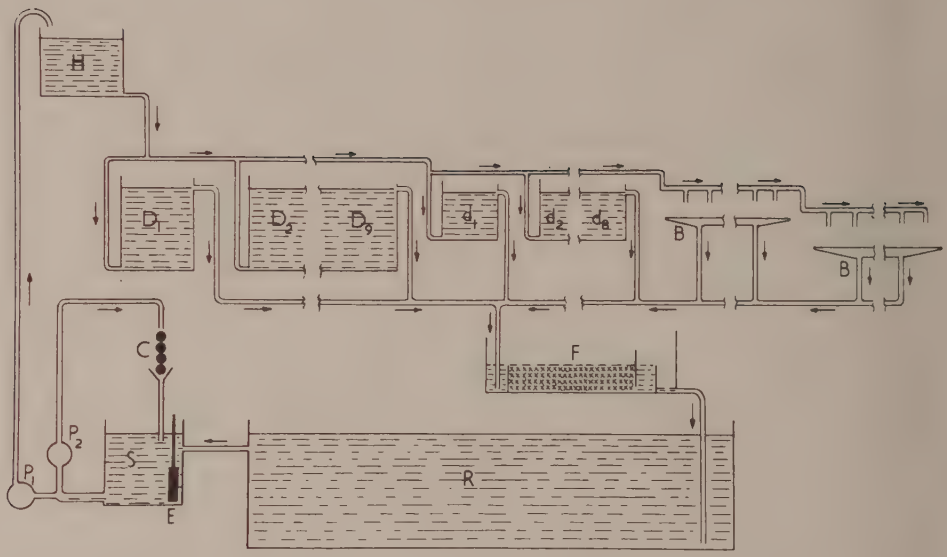

FIGURE 1.—Circulation system of the main aquarium: *B*, experimental benches (high and low); *C*, cooling coils; D_1 to D_3, large display tanks; d_1 to d_3, small display tanks; *E*, immersion heater; *F*, filter; *H*, header tank; P_1, main circulation pump; P_2, cooling circulation pump; *R*, reservoir-sedimentation tank (duplicated); *S*, service tank.

Valves are of the rubber diaphragm type with vulcanite linings (Dexine Rubber & Ebonite Ltd.).

Cut-in/cut-out electrical probes have carbon contacts (stainless-steel probes were found to be unsatisfactory) connected to relays (Sunvic Controls Ltd.).

Air at 10 to 14 pounds' pressure is supplied by a water-sealed compressor (Nash Engineering Company). This avoids oil droplets in the air compressed by oil-sealed pumps. A trap fitted with a float valve collects and drains off the fresh water arising from droplets carried over with the compressed air. Aeration facilities are provided to each tank, but their use is exceptional where tanks are on circulation.

OPERATING DATA

The twin reservoir-sedimentation tanks, each of 40,000 gallons' capacity, are used in the circulation on alternate weeks.

Sea water is added to the system to make up for losses in siphoning and maintenance; to provide the maximum refreshing, any surplus water is run off so that an addition of clean sea water can be made at the rate of 4,000 gallons monthly. Incoming water is added to the tank not on circulation, thereby allowing a period for seasoning. Sea water is transported by lorry in a collapsible Portolite container (Marston Excelsior Ltd., I.C.I.).

The sand filter bed comprising twin sections is wholly in use except for the shutting off of a half section for periodic maintenance. This procedure maintains the filters in a much better condition than alternate use. The pattern of the filter is that normal for domestic fresh-water supplies, but incorporated in the bottom of the filter is a layer of coarse marble chips. This is considered to be responsible for the marked stability of the pH in the aquarium, which has constantly remained

FIGURE 2.—Semipublic part of the aquarium. On the left are the large built-in display tanks illustrated in figure 1, D_1 to D_5; D_6 to D_9 can be seen through the door into the experimental aquarium. Access to these aquariums is by a servicing platform behind the tanks. The center tank is purely decorative. The small display tanks, d_1 to d_8, are on the right.

within the limits normal for water in the open sea. Incorporation of marble has not resulted in any marked increase in the calcium content of the sea water, which is around 425 mg. per liter.

Salinity has remained at around 34 parts per thousand and there has been no occasion to compensate for evaporation.

With few exceptions food is restricted to squid cut to a suitable size and washed. This food has the advantage of being firm, and its use reduces to a minimum the water-soluble and particulate matter which is not taken up by the aquarium animals. Unvaried, it appears to afford a satisfactory diet.

Live material is transported in a carrying tank designed to restrict violent movements of water (fig. 3). When the tank is stocked for carrying, the domed cover is secured in position, and water is added to bring the surface level into the narrow chimney.

Each tank of the aquarium can be isolated from circulation and in these circumstances is furnished with a small portable filter. Sea water is maintained in circulation over this filter by means of an air lift (see also Isolated Tanks, page 25).

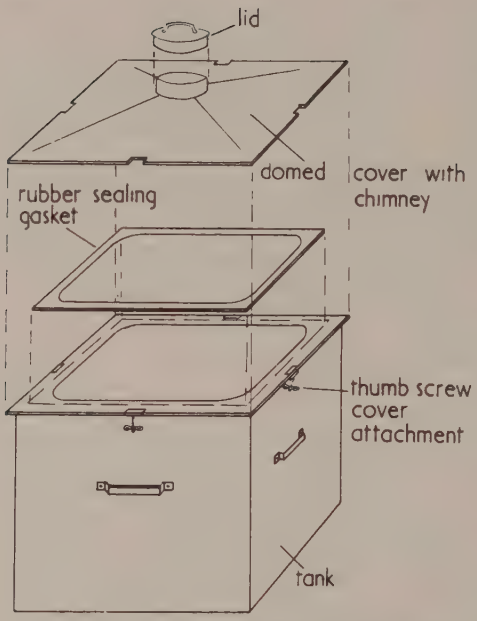

FIGURE 3.—Carrying tank for live material.

TEMPERATURE CONTROL

For general purposes the aquarium water is allowed to take up its natural temperature. In hot weather, however, the maximum temperature is held to about 14° C., whilst in cold weather a minimum of around 6° C. is maintained.

Heating or cooling under thermostatic control is applied in the service tank (fig. 1) which is effectively that section of the reservoir tank from which sea water is immediately drawn to supply the aquarium system. The cooling system is rated to maintain a maximum temperature of 12° C. The heating system is capable of holding 8° C. minimum temperature throughout the aquarium. This allows for the aquarium being run throughout the year at the appropriate seasonal temperature normal to the open sea around Scotland. Alternatively, most of the year, the aquarium can be run at any desired normal temperature between 5° and 16° C. In extremes of climate, such a desired temperature can be held over a part of the aquarium system with the remainder off circulation.

SPECIAL FEATURES

Temperature control is the most frequent requirement in an experimental aquarium. In addition to the general control outlined above, two tanks, each of 700 gallons' capacity, which are normally incorporated in the general circulation, can be isolated, either singly or together, into a separate unit controllable as to temperature within the range 4°–20° C. (figs. 4 and 5). The system alternatively provides an offtake of temperature-controlled sea water to the circulation bench for use with portable tanks. The relevant capacities and ratings for the temperature-controlled system are as follows:

Volume of twin display tanks (700 gallons each)	1,400 gallons
Volume of header heat-exchanger tank	100 gallons
Circulation pump rated capacity	1,000 gallons per hour
Refrigerator rated capacity	27,000 Btu
Heater capacity	6 kilowatts

Experimental procedures frequently demand a sea-water tank controlled to a temperature below room temperature. A small unit (preferably transportable) used for cooling a number of small tanks to different preset temperatures is shown in figure 6. A reservoir of brine, or antifreeze solution, is maintained at a low temperature, and this is pumped through glass cooling coils immersed in the water of the experimental tank(s). The operation of the pump is thermostatically controlled. The number of tanks which can be coupled to this system depends on the regulated temperatures to be maintained. It can be materially increased by insulating the experimental tanks against heat loss.

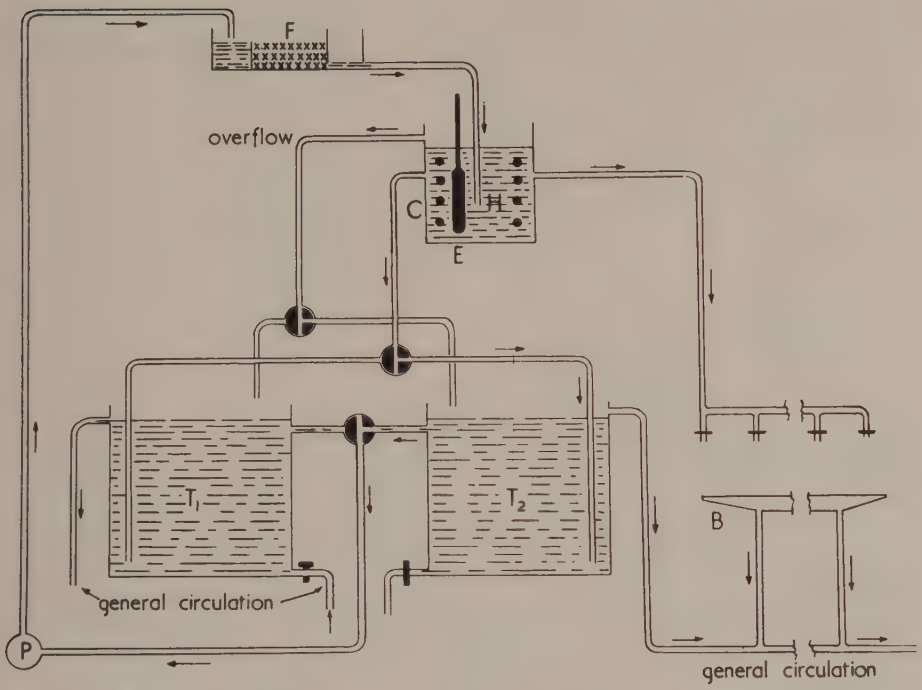

FIGURE 4.—Circulation system of the temperature-regulated experimental tanks: *B*, experimental bench; *C*, cooling coils; *E*, immersion heater; *F*, filter; *H*, header and temperature-control tank; *P*, circulation pump; T_1, experimental tank, depicted on general circulation; T_2, experimental tank, depicted on temperature-control circulation.

ISOLATED TANKS

Experiments frequently involve diseased fish or techniques which may contaminate the sea water. Such experiments must be undertaken in such a way that there can be no risk to the general aquarium circulation, namely, in a separate sea-water tank system. The unit described below has proved most serviceable and consequently is preferred even where the procedures involved are no bar to the use of the main aquarium. The system is simple and relatively cheap to construct.

The unit consists of two reinforced-concrete tanks 12 by 6 by 6 feet, each capable of subdivision by a sectional teak partition (fig. 7). An air lift maintains circulation of the sea water over a sand filter, whence it gravitates back to the bottom of the experimental tank. The base of the filter is at the level of the top of the tank so that the lift is a minimum. Aeration is provided using two Doulton filter candles (Doulton & Co. Ltd.), grade KF, as atomizers. The constructional details follow those outlined for the main aquarium. The tanks and filters are unhoused and fitted with removable covers.

GENERAL

It frequently happens that when an aquarium is in design there are a number of research projects immediately envisaged. Nevertheless it is essential that the

FIGURE 5.—Experimental aquarium. On the left is the low experimental bench; the high bench is in the center. Our aquarium assistant is seen working at a teak-topped bench fitted with hot and cold fresh water and sea water, all running to waste.

basic design be kept simple so as to be as flexible as possible. In this way the inevitable misconceptions in the original research projects will be most readily remedied and thereafter the system be adaptable to the widest possible variety of conditions and requirements.

Successful operation of an experimental aquarium depends upon regular inspection and maintenance of the supply system. We have found this to be greatly facilitated by using standard checklists. Those developed for use with our system are shown below.[1]

[1] Editor's note: These check lists, furnished incidentally by the author for our edification, are included here because we believe that such working details should have great interest to those charged with the day-to-day operation of sea-water supply systems.

DETAILS OF AQUARIUM MAINTENANCE

Daily maintenance

1. Change over all duplicated pump motors (three) and check all other pumps and refrigerator motors in use (12) functionally.
2. Remove dead animals from tanks.
3. Feed aquarium animals as necessary.
4. Check daily diary for experiments being initiated or completed and for arrival of livestock etc., taking the necessary action.
5. Check functionally the aerators in use (two) and the air pressures.
6. Check each tank, including isolated units, for (*a*) air supply, (*b*) level of water, (*c*) rate of circulation, (*d*) cleanliness of the water, and (*e*) cleanliness of the overflow pipe.
7. Check temperatures as shown by recorders (two) and thermostatic control of the system.
8. Check functionally the refrigerator units in use (three), including blower motor and pres-

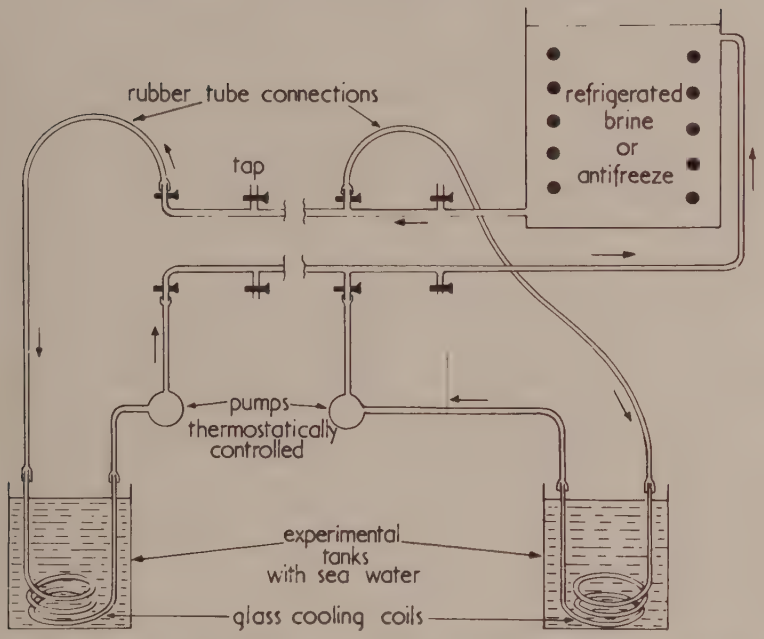

FIGURE 6.—Unit for coling a number of portable experimental tanks to varying controlled temperatures.

sure of the refrigerant. Check the rate of circulation of sea water over the refrigerator coils. Check heater functionally on temperature controlled tanks.

9. Clean up the aquarium and ancillary rooms (pumprooms etc.)

10. Remove any uneaten food material. Siphon off excreta and other debris from the tanks.

11. Make up sea water to the appropriate level in any isolated tanks.

12, Obtain supply of food material as required.

13. Make up daily diary.

Weekly maintenance

1. Take pH of the sea water and adjust if necessary.

2. Take salinity of the water, adjusting for evaporation where necessary.

3. Clean the glasses of the tanks.

4. Change over to the duplicate aerator motor.

5. Renew the sheets in the temperature-recorder units (two). Refill the pens with ink and check the accuracy of the recorder temperature. Check all thermostat controls functionally.

6. Check the level of the water in the reservoir tanks. Arrange for topping up if necessary. Ensure adequate reserves of sea water in tanks and carboys.

7. Change over to the alternate reservoir tank.

8. Clean out the aquarium and ancillary rooms.

9. Check all probes, including the action of the emergency probes, in both header tanks and sump.

10. Check functionally all circuit breakers, overload and other switches.

11. Check functionally all lighting and power points. Clean as necessary.

12. Clean and grease all sea-water pump motors. Check for corrosion. Clean off rust and repaint as necessary.

13. Examine outflow inspection chamber as a check on leakage and inspect pumprooms and all tank rooms for sea-water leakages.

Monthly maintenance

1. Drain, clean out, and reestablish each tank on a 6-month rotational basis.

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2. Examine sea-water filters, renewing small individual filters as necessary.

3. Lift covers to ducts in north-block aquarium and hose out ducts. Clear rust from ironwork and touch up.

4. Clean and grease the refrigerator units (three) and blower motor.

5. Clean and grease aerator units (three).

6. Examine all machinery, lighting reflectors, conduit switches, etc. for corrosion. Clean off rust and touch up as necessary.

7. Remove Sunvic thermostats. Clean housings and control unit. Protect the bimetal strips by dipping in light oil.

Quarterly maintenance

1. Check air filters (three) for cleanliness; renew as necessary.

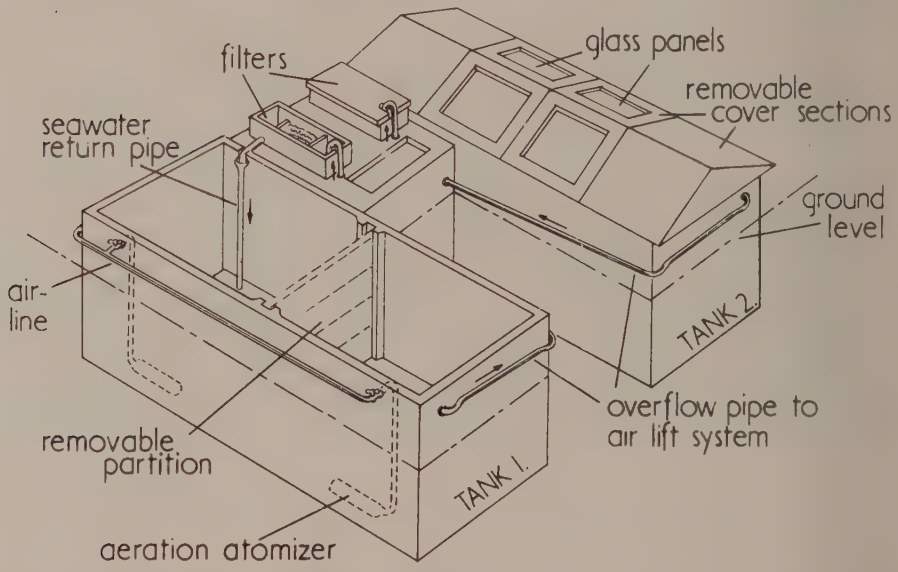

FIGURE 7.—Isolated experimental tanks. The covers to tank 1 and its associated filter unit, as well as the access cover to the inspection pit for the air lift, are removed. The sectional teak partition used to divide the tank is shown dotted in position, as also are the internal aeration pipes and atomizers.

A CLOSED CIRCULATING SEA-WATER SYSTEM

By M. S. Gordon and R. A. Boolootian

Department of Zoology, University of California, Los Angeles, Calif.

Abstract.—The closed circulating sea-water system of the Department of Zoology, University of California at Los Angeles, is described, and some parts are illustrated. Some important changes which would improve system operation are listed. These include changes in construction materials for large water tanks and sea-water return lines, and changes in the types of pumps.

The Life Sciences Building of the University of California at Los Angeles contains a large, closed circulating sea-water system which is used for both research and teaching purposes. This system has a capacity of about 25,000 gallons of sea water and has functioned very successfully since the fall of 1958. A wide variety of marine vertebrates and invertebrates have been maintained in the system for long periods.

STRUCTURE OF THE SYSTEM

The system extends through six floors of the Life Sciences Building. A basement room of the building contains two concrete storage tanks of about 9,500-gallon capacity each, two 1,300-gallon capacity sand gravity filters in redwood tanks, an 1,800-gallon redwood supply tank, associated hard-rubber and polyvinyl-chloride (PVC) unplasticized plastic piping, and several pumps (see figs. 1 and 2). From this basement room the sea water is pumped through a hard-rubber pipe to two 750-gallon capacity redwood gravity tanks on the fifth floor of the building (fig. 3). The water then circulates by gravity flow through hard-rubber and PVC plastic pipes to 3 aquarium rooms and 10 sea-water tables in various classrooms in different parts of the building. From these aquarium rooms and sea-water tables (fig. 4) the water returns to the storage tanks in the basement through Transite pipes.

The water is pumped from the main storage tank in use (one of the two storage tanks is used at a time, the other being kept as a reserve supply of sea water) into the two filter tanks by means of one of two small, neoprene-rubber-lined cast-iron centrifugal pumps (3-horsepower electric motors, Galigher Vacseal pumps, 1½-inch diameter outlet; fig. 2, *A*, *B*). From the filter tanks the water siphons into the central supply tank (fig. 1, *E*), from which it is pumped by a large supply pump (fig. 2, *C*) to the gravity feed tanks on the fifth floor. The head against which the main supply pumps operate is approximately 95 feet. There are two main pumps, but only one operates at a time, the second being kept in reserve. Both main pumps are powered by 10-horsepower electric motors and are cast-iron centrifugal pumps lined with high carbon content neoprene rubber (Galigher Vacseal, 2-inch diameter outlet). The pumps were originally designed for use as slurry pumps in mining operations.

All pipes and fittings in the supply part of the system are fabricated either of hard rubber or of unplasticized PVC. All

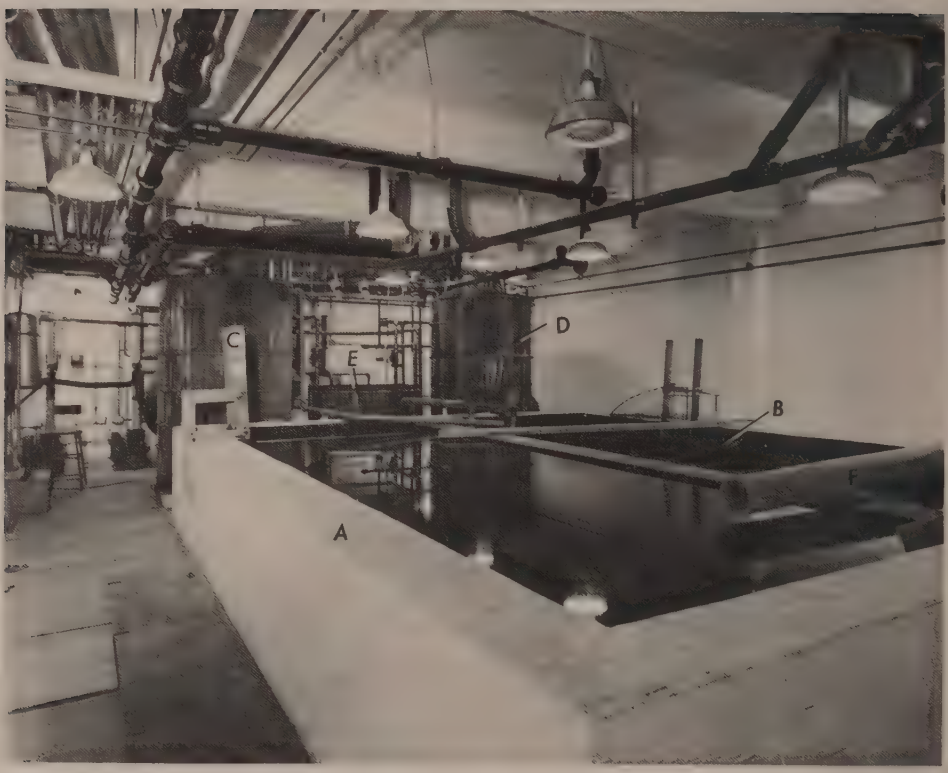

FIGURE 1.—Upper level of the basement pumproom. Sea-water system components include the two concrete main storage tanks (*A*, *B*), the two redwood gravity filter tanks (*C*, *D*), the redwood main supply tank (*E*), and one of two Transite pipes (*F*), leading from openings in the pavement outside the building, through which new sea water is added to the system. The Transite main return line from the building, suspended from the ceiling, crosses the center of the figure. Water returns to the storage tanks at the right-hand edge of the figure. Since this photograph was taken, the interiors of both storage tanks have been painted white with a nontoxic plastic paint. This facilitates their use as aquariums for larger animals.

large-diameter valves are of the diaphragm type, with neoprene-rubber gaskets. Water tables in aquarium rooms and classrooms are fitted with banks of hard-rubber stopcocks (fig. 4). They are also supplied with hard-rubber compressed-air lines. The water tables themselves are constructed of reinforced concrete.

Each of the three aquarium rooms has a large Pyrex glass countercurrent heat exchanger fitted into its sea-water supply line. Each of these heat exchangers is supplied with refrigerated fresh water from individual refrigeration units in adjacent parts of the building. Thermostats allow fixing of the temperature of the sea water leaving each heat exchanger.

Specific setups in the three aquarium rooms and on each of the classroom water tables are modified according to need. There is a general rule excluding all metal from the system. Accordingly, any aquariums with metal frames introduced into the system must be fitted with constant-level overflow siphons. In addition, rub-

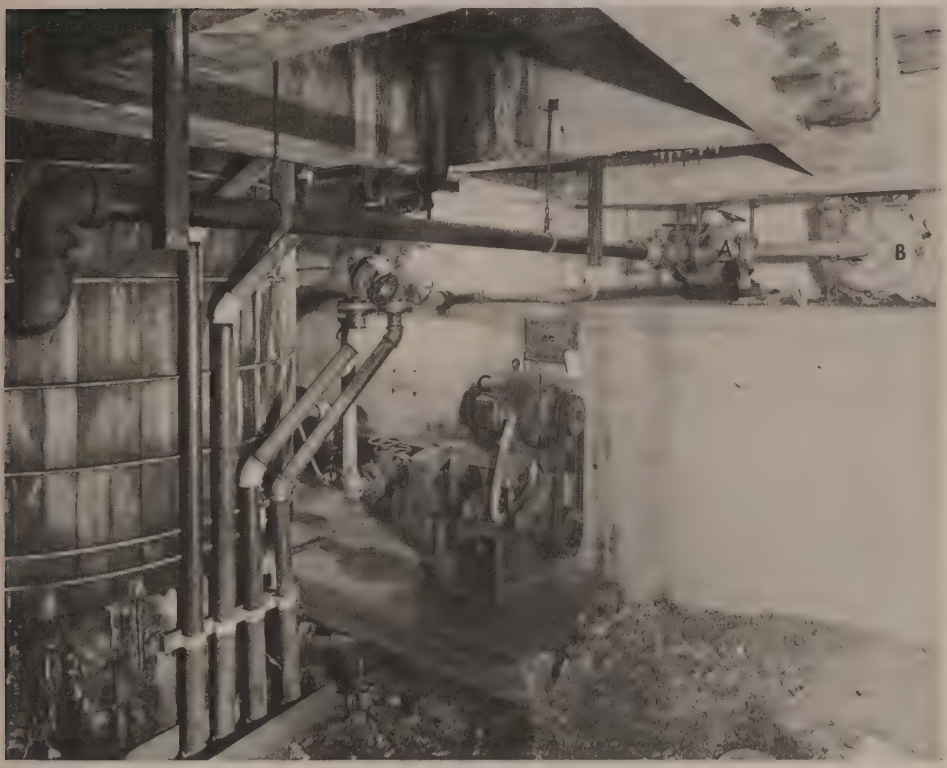

FIGURE 2.—Part of the lower level of the basement pumproom. Sea-water system components include the two small centrifugal pumps which move water from the main storage tanks to the filter tanks (*A*, *B*), one of the two centrifugal main supply pumps which pump water from the main supply tank (base visible on left) to the fifth floor of the building (*C*), and parts of four pipes. Two of these pipes are backflush drain lines for the filter tanks. The other two are bottom drain lines for the filter tanks. The bottom drain for the main supply tank is visible to the right of the lower ends of these four pipes.

ber hoses are avoided, Tygon tubing being used preferentially.

In operation of this system no attempt is made to maintain or control water quality over long periods. The most sensitive of the organisms kept in the system (octopuses, sea urchins, etc.) are used as indicators of deterioration. When signs of trouble appear (animals acting abnormally or dying) all water in the system is replaced with new sea water. The old sea water is drained from the storage tanks in the basement by pipes connecting with sewers. The new sea water is added via Transite pipes opening through the sidewalk outside the building (fig. 1, *F*). We charter stainless-steel milk-tank trucks to transport sea water to the system from Marineland of the Pacific, Palos Verdes, Calif. Sea water replacement is necessary only about once every 2 to 3 months.

One of the major reasons for the relatively long period of maintenance of water quality despite a heavy load of animals is the efficiency of operation of the sand filters in the basement. These fil-

FIGURE 3.—The two redwood gravity-feed tanks on the fifth floor.

ters maintain a considerable bacterial population which seems to remove much toxic material from the water. The only maintenance necessary on these filters is occasional (about every 4 or 5 months) back-flushing of the filters with fresh water. Each filter tank is fitted with suitable fresh-water and compressed-air lines, and back-flush drain lines, for carrying out this operation with minimum loss of sea water.

The system is equipped with an alarm system which immediately notifies the University maintenance department of any interruption in operations. Maintenance men are available on short notice at all times.

RECOMMENDATIONS

As it is, the system functions very well. However, if redesign of the entire system were practical several things would be done differently.

First, we would not use centrifugal pumps as motive power. Centrifugal pumps are relatively inefficient in terms of the amount of power needed to pump a given volume of water a given distance. This is especially true for the rubber-lined pumps we use in order to avoid metallic contamination. Recent developments in pump design have made available several other more satisfactory types of pumps for continuous surge-free operation against large pressure heads. Surge-free

FIGURE 4.—One of the three aquarium rooms showing several reinforced-concrete water tables (approximate dimensions 72 by 22 by 4 inches) and a large fiberglass-lined redwood tank (250-gallon capacity). Note banks of stopcocks on wall, also compressed-air line with multiple outlets.

operation is especially important because hard-rubber and PVC plastic are both brittle and break easily when distorted.

Among the alternative pump designs which seem attractive are gear pumps with Teflon plastic gears and pump-case linings and Archimedes-screw pumps with plastic-coated screws and case lining.

Second, we would not use redwood as a construction material for any tank in the system. Redwood continues to leak colored materials into the water over long periods—this is still happening in our system after over 3 years of continuous operation. This colored material appears not to be toxic or in any way pharmacologically active, but it mars appearance of the sea water and hence interferes with observations. Fiberglass-reinforced plastic or wooden tanks would seem to be the solution.

Third, we would not use Transite as material for return lines. Transite piping is permeable to water and will, therefore, accumulate salt deposits on its outer surfaces if used to transport sea water for long distances through air spaces. These salt deposits do not seem to weaken the transite itself, but can be the cause of important building deterioration if atmospheric water condensation occurs which then results in drip of salt water. The solution is the replacement of all transite with unplasticized PVC pipe.

ACKNOWLEDGMENTS

Continued successful operation and maintenance of this system would not be possible without the able cooperation of the UCLA Department of Buildings and Grounds. Assistant Chief Engineer John Little was largely responsible for the expert and expeditious solution of many problems which arose during the difficult early "shake-down" stages of the operation.

ADDENDUM

In the time since this paper was submitted, new developments have occurred in pump technology which have revised our opinions concerning centrifugal pumps. Several very efficient, reliable, nontoxic centrifugal pumps adequate for the needs of the UCLA system have appeared on the market. The two main supply pumps and one of the filter pumps in our system have been replaced with these. The casings and the impellers of these pumps are made of one of several types of epoxy resin. One of these pumps (a Series P Durcopump, manufactured by Duriron Co., Inc., Dayton, Ohio, powered by a 3-horsepower motor) has now (December 1963) been used continuously as the main supply pump for the system for over 1½ years. There has been no down time, and the pump has required only routine maintenance.

A MEDIUM-SIZED SEA-WATER SYSTEM FOR THE LABORATORY

By J. E. McInerney and W. S. Hoar

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Abstract.—A simple and efficient salt-water system which may be easily constructed from readily available materials is described. Various ways of solving the problems of contamination, aeration, removal of waste products, and temperature maintenance are considered.

The principal problems in maintaining a closed salt-water system in the laboratory are as follows:

1. Avoidance of contamination.
2. Maintenance of adequate oxygen levels.
3. Removal of waste products.
4. Maintenance of temperatures.

The sea-water system described here provides a reasonably simple arrangement of a size intermediate between the typical home aquarium and the large public aquarium. It has operated satisfactorily in our laboratory for many years and has been found useful in maintaining teaching and limited research material. A schematic representation is given in figure 1. Solutions to the problems listed above are achieved in the following ways.

CONTAMINATION

All parts are constructed of wood (filter tanks and aquariums) or rubber or plastic (pump, pipes, and connections). Where it is necessary or more convenient to use metal, these parts are coated with nontoxic rubber- or oil-base paints. If it is impractical to paint exposed metal, then a suitable type of noncorrosive stainless steel is necessary. For example, the pump shaft is frequently constructed of this material.

OXYGEN

Adequate oxygen levels can be maintained in several ways. The most efficient system involves a supply of compressed air delivered through plastic tubing to air stones with plastic rather than metal stems. As an auxiliary source of aeration, the water returning from the elevated filter can be sprayed back into the aquariums. Similarly the water supply to the filter can be sprayed onto the filter bed by taking advantage of the pressure supplied by the pump. The amount of aeration required is a matter of experimentation depending mainly on the temperature of the water and the number of animals.

WASTE MATERIAL

A useful and simple filter arrangement is shown in figure 1. Water is removed from a point as far as possible from the clean-water inlet. It is pumped by a self-priming plastic pump to the elevated filter tank. An intermittent rather than continuous pumping action is achieved by using a plastic float (in our case, a toilet-tank float) in conjunction with a mercury switch (similar to those found in furnace thermostats). Details of this system are shown in figure 2.

The filter bed may be constructed of any

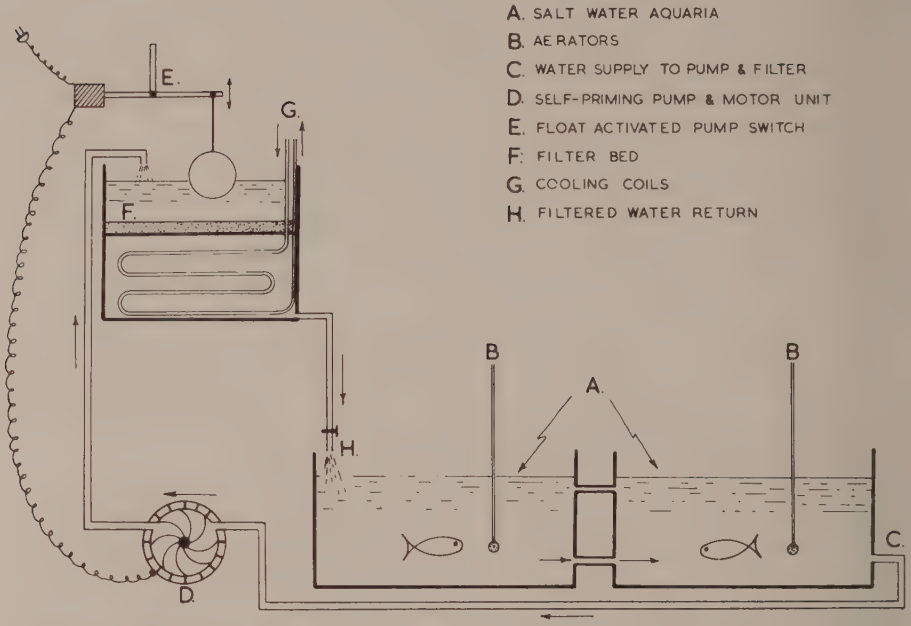

FIGURE 1.—Salt-water system: *A*, salt-water aquariums; *B*, aerators; *C*, water supply to pump and filter; *D*, self-priming pump and motor unit; *E*, float-activated pump switch; *F*, filter bed; *G*, cooling coils; *H*, filtered-water return.

suitable nontoxic material. Two types are illustrated in figure 2. Successive layers of finer and finer gravel beginning with the coarsest gravel or rock at the bottom provides the least expensive method of filtration (fig. 2, *1*). Cleaning this filter bed involves running fresh water into the bottom and up through the sand and gravel to the top of the tank (fig. 2, *3*) to waste through an overflow outlet (fig. 2, *4*).

A simpler disposable filter is made from two thicknesses of industrial fiberglass battens (fig. 2, *2*) mounted on an appropriate frame. The frequency with which the fiberglass must be washed or changed will depend mainly on the number of animals in relation to the surface area of the filter bed.

TEMPERATURE

With a closed salt-water system there must usually be some means of keeping the water sufficiently cool. The simplest and least unsightly method is illustrated in figure 2. A supply of cold tap water is circulated through plastic or, for more efficient heat transfer, stainless-steel coils mounted below the fiberglass filter bed (fig. 2, *5*). With a graded-rock filter the coil may be included directly in the filtering material. More precise temperature control may be achieved by using either a complete refrigeration system or by operating a thermostatically controlled heater in opposition to a continuous source of cooling such as the cold-water coils suggested above.

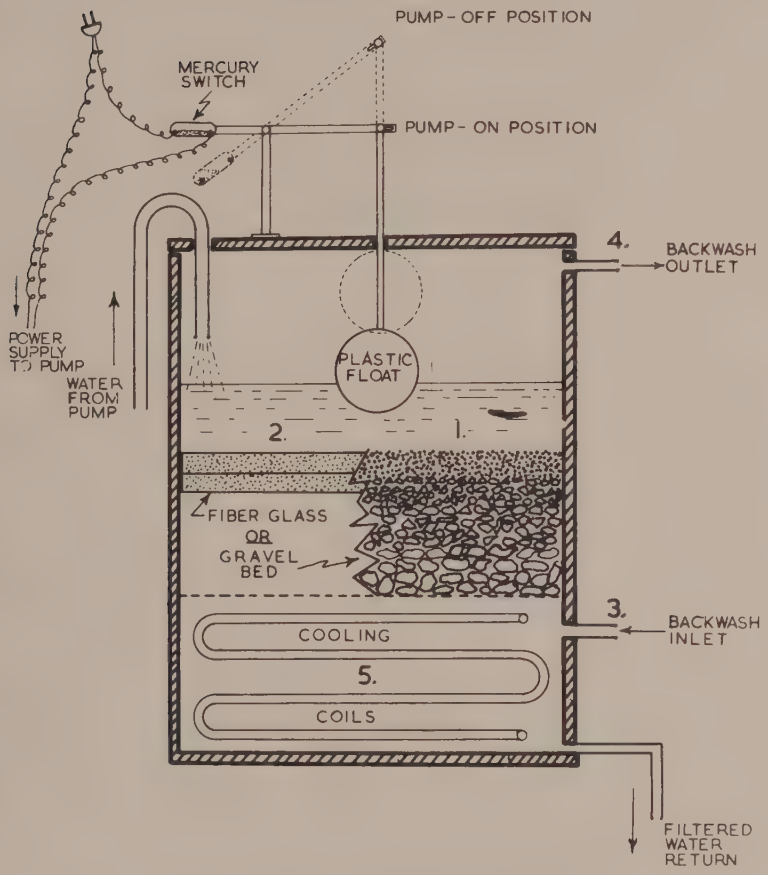

FIGURE 2.—Filtering and cooling details.

Alternatively, the cooling coils (glass tubing is satisfactory) may be included in the aquariums or the aquariums may be surrounded by a bath of running water.

The system illustrated here may, if desired, be very simply constructed of materials found in most laboratories. A wooden barrel will serve as a reservoir, and ordinary glass aquariums may be set in series with water siphoned from one to another. If the pump is located below the aquariums, it need not be self-priming. Our filter tanks are about one-third the capacity of the associated aquariums, but this is largely a matter of convenience since the rate of filtering can be adjusted.

MINIATURE CIRCULATING SYSTEMS FOR SMALL LABORATORY AQUARIUMS

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Abstract.—Methods are given for constructing both an open system, wherein the sea water runs to waste, and a closed system, wherein the water is recirculated. Easily available materials are used, and all devices, such as a constant-level siphon and an automatic shutoff, are simple to assemble. Each of the systems is designed so as to require a minimum of maintenance. Equipment necessary for the control of sea water is discussed.

Because of the requirements of certain experiments it became necessary to establish various small, but fully controllable circulating systems in small aquariums. These have included both open and closed fresh-water systems and closed salt-water systems. As the designs eventually worked out have proved to be entirely satisfactory, and as many colleagues have inquired about these systems, with a view to building similar ones for their own purposes, the details of construction and operation are explained here.

Primarily these systems are the outgrowth of work of earlier years at the old New York Aquarium, where much larger, but similar, equipment formed the basis of operations. This equipment itself had been developed from schemes used by older institutions of similar kind. Naturally, many persons had a hand in developing the arrangements and devices employed at the New York Aquarium. For these reasons the origins of the devices were not always clear, but those chiefly interested and responsible for them at the Aquarium were C. W. Coates and the late C. H. Townsend, and H. Knowles. Townsend (1928) and Breder and Howley (1931) reported on some of these features. It has been found that by suitable modification of the principles of the larger devices it is possible to develop very useful miniature equipment. Such need, of course, applies only to laboratories which are not connected with large public aquariums and which consequently lack the utilities usually to be found only in such places. These devices have been worked out in connection with experimental work carried on in the laboratories of the Department of Fishes and Aquatic Biology of the American Museum of Natural History, which has been supported in part by the National Science Foundation.

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OPEN SYSTEMS

An "open system," as the term is used here, is one in which the water is used once and is not recirculated; there is only a supply line and a drain line. This calls for little comment in present connections except where a very small, well-regulated flow is required. Such apparatus may be

arranged to provide as little as a specified number of drops a minute, and will maintain a surprising accuracy if properly designed.

The overflow provided for this system is a constant-level siphon. If such a siphon is made by a glass blower, it will be expensive, subject to breakage, and not readily cleaned. A siphon can be made quickly and cheaply of some straight glass tubing, a tee, some flexible rubber or plastic tubing, and two small strips of wood or plastic. No dimensions are given, as these will vary with the individual needs, although figure 1 is drawn to scale. The two strips of plastic are identical; each has two holes drilled in it to fit the glass tubing snugly. The parts are assembled to make a constant-level siphon attached to the lip of an aquarium as shown in figure 2. The lower piece of plastic may be fastened to the aquarium by small clamps or may be cemented to it. The open, upper end of the tee vents the siphon. If a cap or plug is placed on this it immediately becomes a simple siphon and will drain the aquarium to the level of its inlet tube. This is sometimes found to be an added handy feature. The level of the water in the aquarium will be that at which the overflow water spills out through the horizontal leg of the tee. Adjustments of this to a fine point may be made by raising or lowering the tee through the hole in the plastic support, or this whole external assembly may be moved up or down by altering the position of the straight length of tubing which passes through the hole in the other piece of plastic connecting it with the tube inside the aquarium. By arranging the outside part of the siphon to lie along the aquarium wall, as shown, the danger of its being in the way of operations is reduced.

Cleaning presents no problem with this type of siphon. If something does nevertheless block the siphon tube from the aquarium, it almost always can be cleared by blowing into the open end of the tee and restarting the siphon by drawing on this same open end of the tee while the outlet tube is held shut. It is possible and sometimes more convenient to attach the outer portion of the constant-level

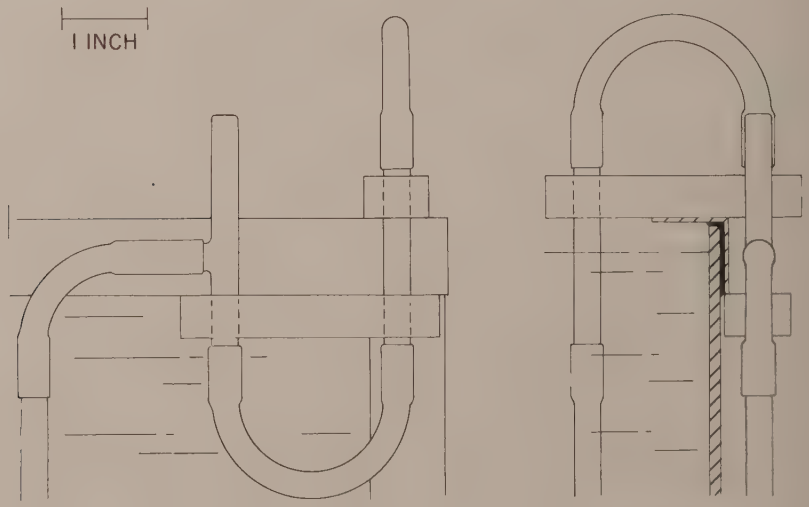

FIGURE 1.—Side and end view of constant-level siphon made up of sandard parts.

siphon to a small board which is affixed to a pivot at its upper end so that it is free to rotate on the stationary part attached to the aquarium frame. A small handle pointing upward from there makes its adjustment simple and marks on the latter in reference to some stationary part make return to a former rate of flow exactly possible. The action is simply that by rotating the part of the siphon so that the horizontal part of the tee raises or lowers, the level in the aquarium follows accordingly. This in turn affects the float valve, which is described below. The rate of flow will increase if the siphon outlet is lowered and decrease if it is raised. This is useful where the exact level of water is not of any importance but where it is desired to vary the amount of water flowing through the aquarium by specific amounts and where it is necessary to repeat such changes in flow at will.

If the water supply has considerable pressure, such as is ordinarily encountered in city water systems, or approaches it, a pressure-reducing valve which may be regulated should be employed. This can bring the pressure down to a value which will not burst or otherwise destroy the light equipment to be employed. This valve placed someplace in the supply line should be set so as to deliver little more than the maximum amount of water which will be required of it. Another way to accomplish the same purpose is to permit the supply water to run into a small reservoir of no more than sufficient height to provide enough head of pressure. Into this reservoir the supply water is allowed to run continually, of a little more volume than the aquariums will ever need. This is necessary to maintain a constant head in the reservoir. A small excess will overflow and go to waste by this method. It is

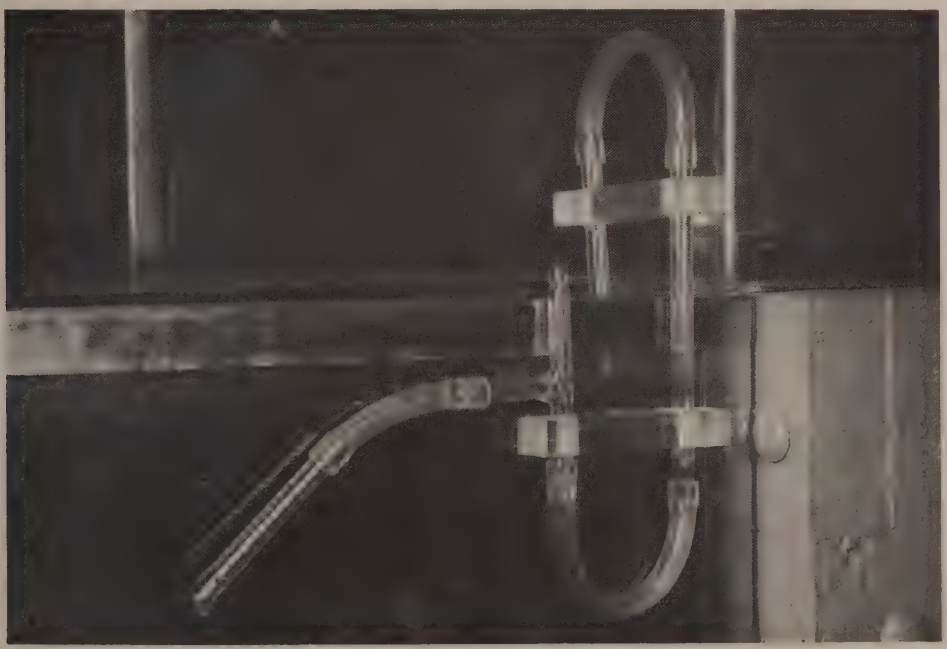

FIGURE 2.—Constant-level siphon in operation.

economical only where water saving has no significance.

The water flowing into this aquarium is controlled by a float valve constructed of a glass stopcock, a suitable-sized chemical flask, and some small parts of either wood or plastic. These are assembled as shown in figure 3 and are held together by iron screws and two pieces of strip steel. This metal is mentioned because of the danger of toxic salts forming if brass were used, since such corrosion might fall into the aquarium. A 1-hole cork is bolted to a piece of lucite and then inserted into the mouth of the flask as shown. A dowel or plastic rod is inserted in the other hole in the plastic piece and secured. A similar piece of plastic is movably secured on this rod and on a similar one at right angles to it, extending from the valve. This is so arranged that the center of the flask comes to rest directly below the horizontal rod extending from the valve. This is best seen in the plan view of the device. By loosening the two setscrews in the upper plastic piece the flask may be moved vertically on the one and horizontally on the other. Figure 4 shows one arrangement of this device.

The extending glass tubes which are an integral part of the stopcock are inserted through two snug holes in the wood or plastic endpieces of the valve, and these are held in position by the two steel strips which are held in place by four wood screws. In the center of one of these steel pieces a hole is tapped into which is screwed a setscrew with a pointed end (about 60°) and a locknut as shown. The stem handle of the stopcock is imbedded in a piece of wood cut about as shown. For this purpose a suitable space is hollowed out in the block into which the stem is inserted, the space around being filled with plastic wood or a similar product. The face of the block and the stopcock stem must be at right angles. On the outer face of the block a small steel strip is affixed with a small drill-tip impression at its center on the axis of the stem. Into this the pointed setscrew fits as shown. This is adjusted so that the valve works freely without being too tight or leaking. This prevents the glass stopcock from working loose and leaking after long-continued operation. The diagonal dotted line on the block indicates the position of the hole through the plug as well as that of the handle on the stem. It is shown in a position just fully closed. It is obvious that with a fall in the water level the valve will open proportionally to the change in water level and shut itself off as the water level rises.

The interaction between the constant-level siphon and this valve is indicated in figure 5. It is clear that danger from flooding could come only from some damage to the equipment. If, for instance, something clogs the overflow in any way, the float valve shuts itself off when it has reached the predetermined point for which it has been set.

As an extreme point of precaution a safety alarm or shutoff could be built as an entirely separate system. Such a device, which has never failed so far as the writer's experience goes, consisted of an old pair of contacts such as are to be found on relays, to one member of which was fastened a shell vial. This hung over the water in such a manner that when the water rose over a specified place it lifted the vial and pushed the two contacts together. It operated on two dry cells to ring a doorbell but could be used with a relay to switch on house current to operate any suitable device. This could be a normally open solenoid valve placed in the supply line. Such extreme caution would only be warranted where a little flooding would be disastrous.

It is obvious that this float valve could be used under certain experimental pro-

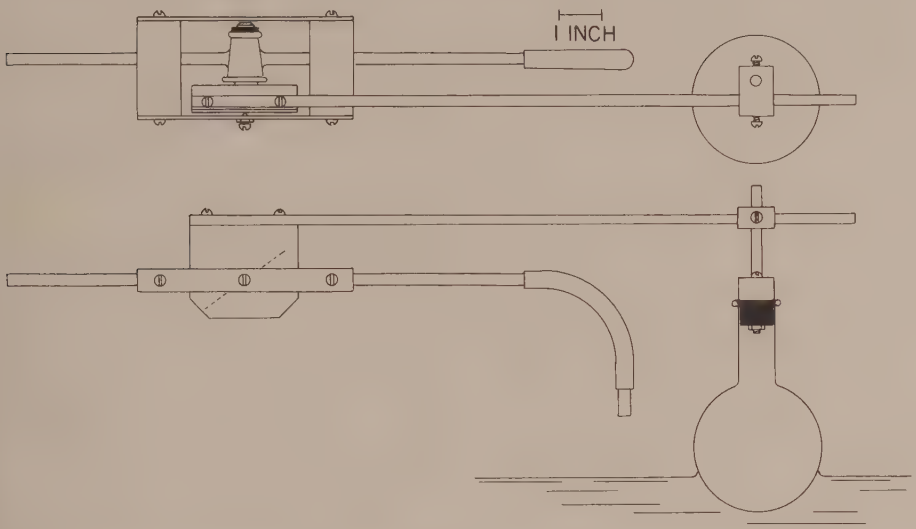

FIGURE 3.—Top and side view of float valve for control of inflow of water and additives.

FIGURE 4.—Float valve for control of inflow. This is the arrangement in the closed salt-water system; the placement is for convenience, but usually valves are placed close to one end.

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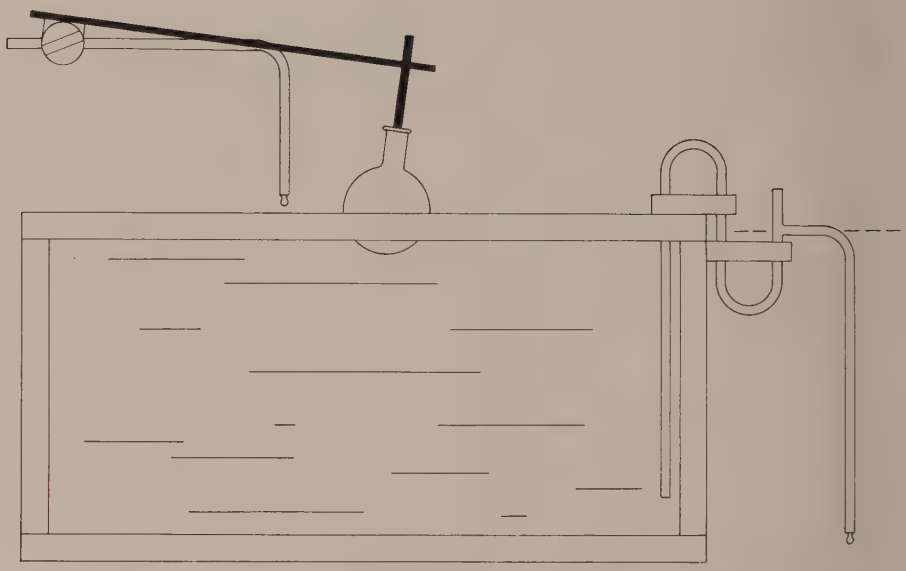

FIGURE 5.—Diagram of interaction between float valve and constant-level siphon. Dashed line represents level of water in aquarium and siphon arm.

cedures to add chemicals to an aquarium at a prescribed rate by inactivating the float and fixing the rate of flow by hand. It also could be used to bring the concentration of some chemical to a fixed limit and then hold it at that point in flowing-water aquariums. The water supply would operate as above described and a second float valve regulated to add much less chemical than the water flow would move with it and act as a follower to the other if there was any fluctuation in the flow of water, thus holding the additive in proportion to the change of water. Also a single float could be arranged to operate the two valves in proportion to the setting of each.

While the designs of these float valves have varied from time to time, all have embodied the same principles as herein described. The first and somewhat primitive one has, at this writing, been in service continually for more than 4 years and is still entirely satisfactory and dependable.

CLOSED SYSTEMS

The term "closed systems" refers to circulating systems in which the water is returned to the aquariums after filtration or other treatment and none is allowed to run to waste during normal operations. Some such system is mandatory for the maintenance of marine forms remote from a ready supply of sea water, and often convenient or necessary for various experimental procedures involving fresh-water aquariums. This is especially true of cases where it is necessary to maintain close control of some feature such as temperature, chemical quantities, and the like. By use of such means it is possible to maintain a series of aquariums with absolutely identical water conditions, as the water in all is part of a common body. Consequently no matter what transpires in one aquarium there is no opportunity

for the water of that one to depart from the characteristics of the rest since it is moving freely from one aquarium to the other and is being continually and effectively mixed.

An especially useful arrangement for some purposes is one in which the flow between aquariums may be continuously varied from maximum in one direction through zero flow to maximum flow in the opposite direction. This may be readily accomplished by the adjustment of four valves while the pump runs continuously in one direction at constant speed. The details of the arrangement of these valves are shown diagrammatically in figure 6.

Figure 7 is a photograph of such a device. In operation the action is as follows. With valves *A2* and *B1* closed and the others open, the flow is out through pipe *A* and returns through pipe *B*, as indicated by the arrows, at maximum flow. If these valves are reversed so that *A1* and *B2* are closed and the others open, the flow through pipes *A* and *B* is reversed, although the flow through the pump remains as indicated by the arrow on it. To pass uniformly from the first position, as shown in figure 6, through a state of no flow to the reverse, either valve *A2* or valve *B1* can be gradually opened. This reduces the speed of water movement because of "back leakage." After one of them has been opened fully, the opening of the other can further retard flow. When it, too, has been fully opened, that is, with all valves fully open, there should be no flow through pipes *A* and *B*, as there is as much pump pressure in one branch of both *A* and *B* pipes as in the other. Then by beginning to close either valve *A1* or valve *B2* the flow begins to move in the opposite direction. When these two are fully

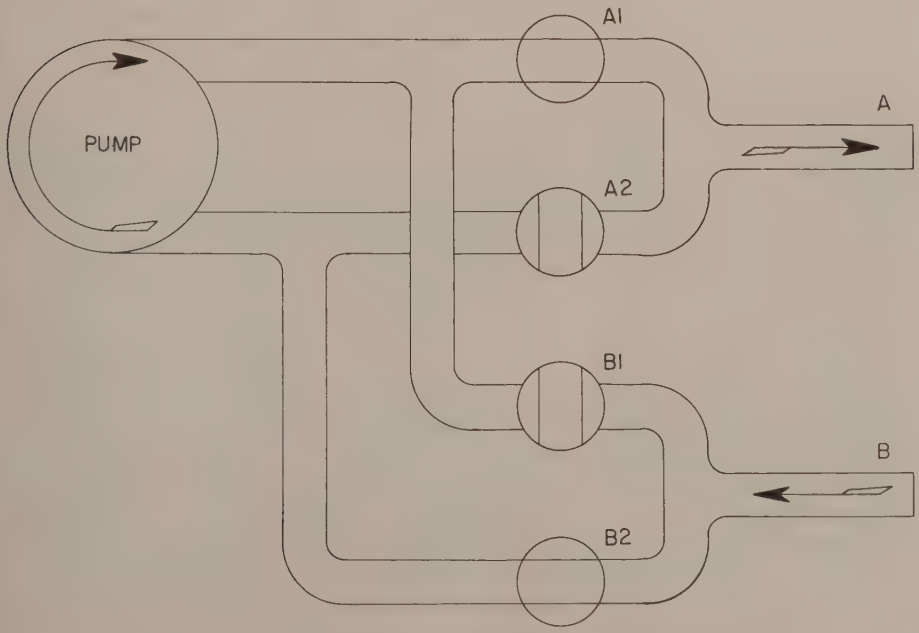

FIGURE 6.—Diagram of piping and valves for continuously variable flow from maximum in one direction through zero flow to maximum in the opposite direction.

closed, the maximum flow in the opposite direction has been reached.

If three valves are arranged on either line *A* or line *B*, or such a set on both, various water-treatment devices may be placed in the series, such as a heating or cooling device, in which case the water may best be passed through a glass coil for heat exchange. This arrangement could equally well be used for any kind of decontamination which might be required or for the introduction of specified materials being mixed with the passing water. Unlike most aquarium plumbing, in this case the water must pass from one aquarium to another, so that as many as may be needed can be placed in series.

A diagram of a more usual arrangement for a closed circulating system is shown in figure 8. This is the form which is perhaps most useful for general laboratory purposes. Here each aquarium is supplied and drained directly from a common supply and return. It is advisable to use a pump of somewhat greater capacity than needed for the purpose. With this means the excess water can be returned to the reservoir without passing through the aquariums, which greatly assists in the efficient application of whatever water treatment is being given and insures adequate pressure for the system. Simple filters may be made by wedging a piece of glass in a small aquarium and filling the intake side with suitable filter material, while the reservoir may be used for whatever chemical or other treatment is to be applied. Two may be provided, as shown in the figure, and used alternately or together. A constant-level siphon takes the water to the first reservoir aquarium. Only one siphon is shown, which may be switched to the other aquarium for cleaning purposes.

The pipes and fittings used in this system are standard hard rubber. Connections between aquariums at the same level may be made by "jumpers" which are preferably of hard rubber. Their use is indicated in the lower-level aquariums

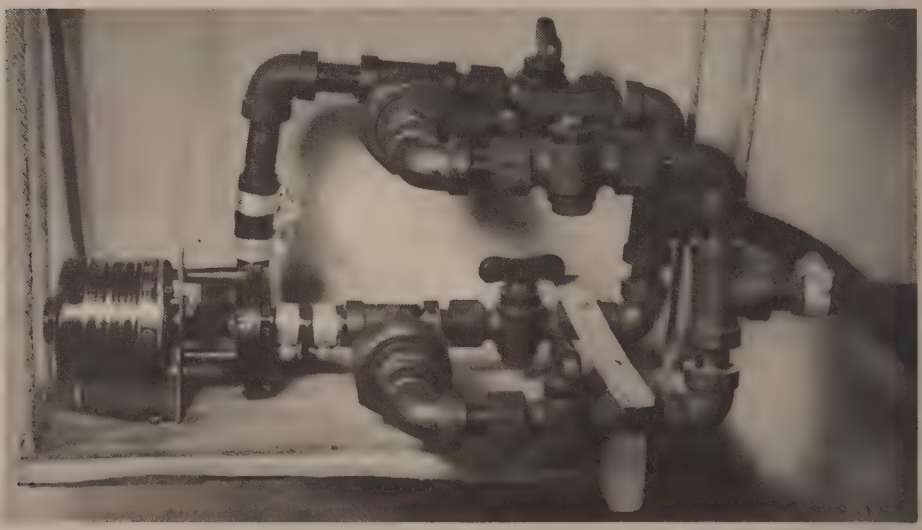

FIGURE 7.—Pump provided with reversible-flow device. The plastic pump here shown is powered by a 1/80-hp. motor and is rated to deliver 3.7 gallons per minute at zero head.

shown in figure 8. These have been found to be fully satisfactory and in several years' operation have not clogged nor have they become airbound. They are, however, not suitable for the overflow lines of the upper series of aquariums. Here constant-level siphons may be used as shown in figure 2, or, preferably, a hole may be drilled in the slate bottom of each aquarium and a 1-hole rubber stopper holding a glass tube inserted. Still better is the installation of a hard-rubber standpipe locked in place with fittings. The drilling of slate is not easily accomplished and there is considerable danger of cracking or otherwise damaging the aquarium. The manufacturers will supply aquariums with such holes drilled on order.

Since the supply to the aquariums of this system is preferably from the top, as indicated, the drain line as above described may be made to draw water from the bottom of an aquarium by the following simple means. A tube of glass, or other material, of larger diameter than the drain tube and as long as the depth of water in the aquarium, is placed over it, reaching nearly to the bottom of the aquarium. Since the larger tube extends above the surface, water leaving the aquarium must enter the annular space between the two tubes and pass up between them to spill into the open upper end of the inner tube. In addition to giving the aquarium a better circulation, much detritus is drawn up through this arrangement and delivered automatically to the filters. The outer tube, if of glass, may be positioned by slipping a short piece of plastic tubing on its lower end and cutting various openings or notches in the plastic. The area of these passages should of course be at least equal to the cross-section area of the inner tube. The annular space between the inner and outer tubes should also have this much area, at least. On the other hand, it is best not to make the annular space much larger than needed because

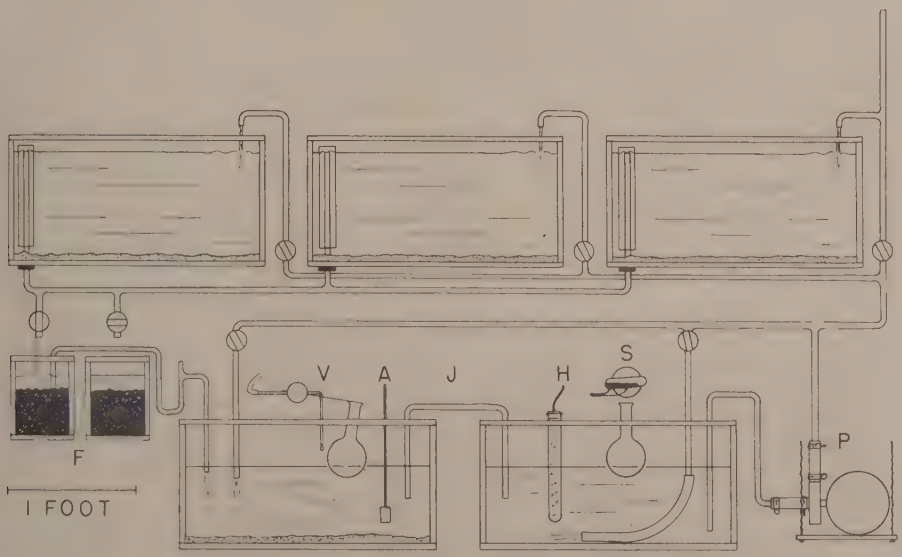

FIGURE 8.—Arrangement of a closed circulating system suitable for small marine aquariums: *A*, aeration outlet; *F*, filters; *H*, heater and thermostat; *J*, jumper; *P*, pump on hanging support; *S*, safety cut-off switch; *V*, float valve. The distilled-water supply carboy is not shown.

this will cause the water flowing through it to move with less speed. The value of this arrangement as a detritus remover is thus lessened, for the slower-flowing water will not lift as heavy particles as will the faster.

As such a system is usually intended to be operated continuously for long periods without attention, a safety feature may be built in which would shut down the pump if the water in the reservoir should rise too high or fall too low. The one in current use, shown in figure 9, was improvised from the tube of a mercury switch. This was mounted on a rotatable glass shaft running through a support of plastic. It was actuated by a chemical-flask float by means of a thread over a small drum so that the motion of the float was transmitted to the pump switch. Any unusual change in the water level, either positive or negative, would indicate some radical failure at some point in the system. Since the aquariums which held the fish were drained by an overflow, they would continue to hold their water level so that stopping the pump would insure the retention of water there. Even if one of the aquariums leaked and lost its contents the others would not suffer by draining through the system to it because of this protective device.

To prevent normal evaporation from stopping the pump, a supply was provided

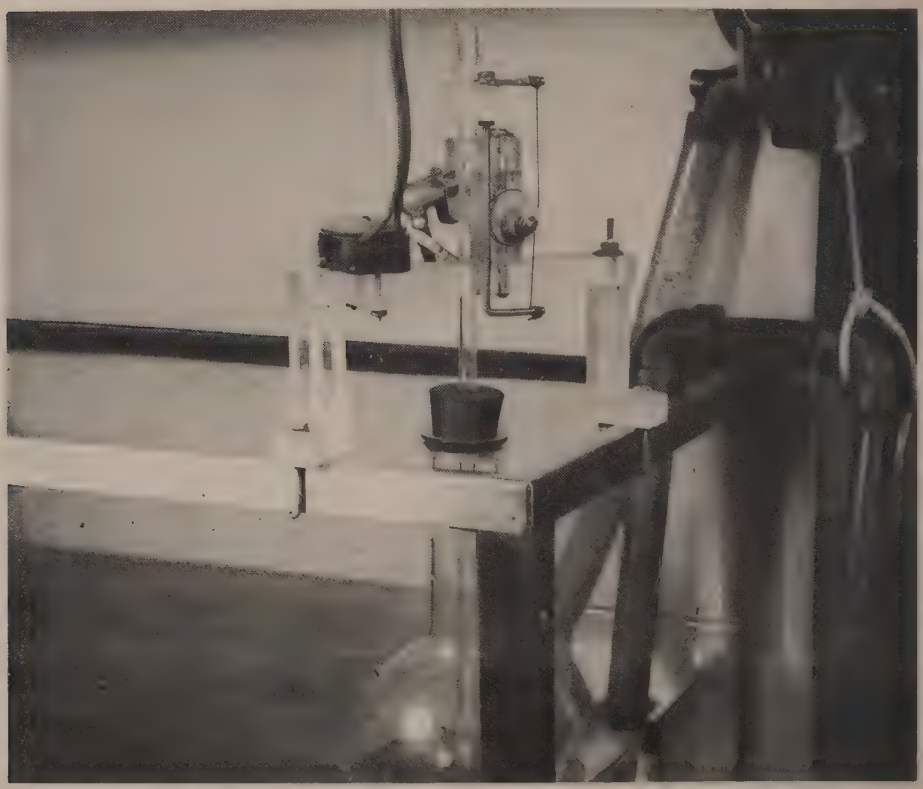

FIGURE 9.—Safety control for closed circulation. Its relation to the system is indicated in figure 8. At the right are the pump intake and excess return.

which operated in conjunction with the protective switch. This supply was administered by a float valve identical with that shown in figure 3. A very nice adjustment was found possible with these two float-actuated mechanisms, so that the dripping from the float-valve supply became directly proportional to the evaporation, without at any time tripping the protective cutoff float valve. On very humid days it could be seen that the number of drops per minute was notably less than on a clear dry day when evaporation was high. In the case of salt-water aquariums this device had an added important application which is discussed under the treatment of salt water.

Because of the nature of the controlling devices above described, it is necessary to observe certain details in starting the system. The levels of water in the lower series of aquariums will be different when the pump is not running than when it is in operation. This is mostly because the drain lines of the upper series of aquariums empty themselves into the lower aquariums when the pump is stopped. Therefore, the water is carried at a lower level in these aquariums so that there will be no overflowing when the circulation has been stopped. For this reason a switch should be shunted around the cutoff float to be used in starting the system before the operating level is reached. It will not suffice to wedge the float into a position where its switch will be closed, because its free action is necessary to establish its proper level of operation. After a dynamic equilibrium has been achieved by adjusting both the cutoff device and the density-control device, the shunt switch should be opened, after which the system should control itself. If it does not at first, very obvious adjustments of either or both will bring them into the proper relation.

The diagram of the closed marine circulating system shown in figure 8 employed seven aquariums for holding experimental fishes, only three of which are shown in the illustration. Three "reservoir" aquariums were used, of which only two are shown. These were standard commercial aquariums measuring 2 by 1 by 1 feet. The two smaller, used as filters, measured 10 by 8 by 6 inches. The pump was driven by a 1/10-horsepower motor and was rated at 10.8 gallons per minute at zero head. The pipe sizes are not indicated, as they would naturally vary with the needs of each system. In this one, the flow was slow but sufficient at about 3 gallons per hour through each of the seven top-row aquariums. At the right of figure 8 the supply pipe is extended upwards for some distance and with the upper end open. This permits building up whatever head of water is desired without subjecting the pipe to pressure greater than that produced by gravity.

Although the upper series of aquariums were intended for holding fishes and the lower series were regarded as treating reservoirs, the latter too may be, and have been, used to hold fishes, that is, all but the one from which the pump draws water, since the suction and turbulence here would be destructive to most small fishes. Aerating stones and a standard aquarium glass heater and thermostat comprised the rest of the water-treating equipment. The heater, which turned off when the water reached 74° F., was sufficient to keep the water throughout the system close to that temperature as it was only slightly higher than the normal room temperature. It was found that the aerating stones made it possible to permit the flow of water in the lower aquariums to run through submerged pipe outlets and thereby reduce the amount of splashing and consequent salt deposits. This was not found necessary in the upper series, for each supply pipe carried only one-seventh of the flow in the lower pipes.

MATERIALS

It is strongly recommended for all the purposes for which these devices were developed that only hard rubber or some biologically inert plastic be used. In fresh water, iron plumbing is adequate for many purposes, but for sea water no metals whatever should be used if any degree of satisfaction is to be obtained. Hard-rubber and acrylic-resin or vinyl chloride-acetate copolymer plastics have been used throughout for those parts which come in contact with the water, including the pumps. Also it is important to see that no brass or other such metals are used in positions over the aquariums in order to prevent possible corrosion falling into the water.

In all cases involving the use of pumps for aquarium purposes it is best to have a spare standby duplicate pump and motor unit as a precaution against the failure of either motor or pump. It is then possible to change such a unit in a few minutes, in the case of accident, with no serious interruption to the operation of the system. It is most convenient to use flexible connectors between the pump and the rigid plumbing leading to the aquariums. It is then necessary only to unfasten two screw clamps and insert the new unit in place. This type of arrangement is shown in figure 7.

An additional advantage of this kind of connection is that it dampens any vibrations from the pump or motor, which tend to travel throughout the system along rigid connectors. The pump in figure 7 was suspended by four light cords, a means which is also very effective in quieting such small machines.

TREATMENT OF WATER

The treatment of fresh water for aquarium purposes is too well known to warrant comment in present connections and is usually necessary only under special situations. The maintenance of sea water in a satisfactory condition is quite another matter. It is not the purpose here to discuss the theoretical aspects of the chemical and physical conditions of sea water. Such matters may be found extensively treated by Sverdrup, Johnson, and Fleming (1942) and Harvey (1955). The following is intended purely as a guide for the practical application of principles which have been found adequate to maintain a variety of marine fishes. Under this treatment regular reproductive behavior was quickly established in both *Histrio* and *Bathygobius*, which had been reared from juveniles. It also permitted a variety of volunteer algae and microorganisms to establish themselves. Incidentally these aquariums were kept under conditions of no daylight, the illumination being supplied by fluorescent tubes of the "warm white" type necessary for satisfactory plant growth. The periods of light and darkness were controlled by a time switch.

The equipment found necessary for the control of sea water consisted of a small hydrometer, a colorimetric pH device, and some simple titrating equipment.

The filters were provided with bone charcoal, and the bottoms of the aquariums and reservoirs were floored with so-called coral sand, and aerating stones were placed in various convenient places, but not in the aquariums containing fishes.

The specific gravity and pH were taken every day until the rate of change was established and from then on were taken at less frequent intervals. This rate of change will vary with the quantity of water, the bulk of the organisms contained, and the temperature of the water. At less frequent intervals titrations were made to determine the variously called excess base, titration alkalinity, or alkaline reserve. This method, which measures the bound CO_2, is not especially accurate but is sufficient for the present

purposes. It consists in titrating a sample with N/100 hydrochloric acid to which brom-cresol purple has been added as an indicator. After the purple color has vanished, the sample is repeatedly boiled and further titrated until the purple color no longer reappears on heating. If the sample consists of 100 cc. to which five drops of indicator have been added, the final burette reading in cc. multiplied by 0.1 gives the bound CO_2 or bicarbonate in millimols/liter. This method is not to be generally recommended for accurate work but is sufficient as a comparative measure of how far and how fast the aging water is departing from its original value.

With this information, corrective measures may be taken. The specific gravity is nearly taken care of by automatic means involving the use of the float valve already discussed. Under normal operations distilled water is used to make up for the evaporation of sea water, which of course tends to increase its density thereby. This has been satisfactorily supplied from a 5-gallon carboy on a shelf higher than the float valve. The operation of the float valve holds the amount of water in the system at a constant volume, which means also that the dissolved salts will remain at a constant amount. If it is desired to increase the density of the water, instead of using distilled water as an additive, sea water may be used until the specific gravity has reached the desired level. If it is desirable to reduce the salinity, water may be withdrawn from the system while distilled water is used in the float-valve supply. This may be conveniently accomplished by means of a siphon with a small hose clamp so that the flow is restricted to a drip slow enough to permit the float valve to follow. Although distilled water was customarily used, in its absence tap water was used with no detectable effect on the fishes or the system.

If the pH falls to lower values it may mean that there is an increase in the amount of free CO_2 present. This could indicate too many organisms for the volume and temperature of the water or too much decomposition for the antacid components of the system to dispose of rapidly. The calcium carbonate in the sand should react with the acids formed, and unless there is overcrowding this type of decreasing alkalinity usually does not present a problem. If the placing of fresh activated bone charcoal in the filter results in an abrupt increase in the pH, it is almost certain that there is too much free CO_2 present. The use of charcoal renewed at short intervals will bring the CO_2 content down, but the charcoal rapidly becomes saturated and cannot be thought of as a regular part of the regulatory process. An increase in the number of aeration stones or amount of air they pass, while much slower in its effects, is a much more satisfactory way to insure against the accumulation of CO_2.

If, on a falling pH, none of the procedures above mentioned increase the pH significantly, the titration reading should be carefully checked and it too should show a decrease. This would indicate a lowering of the bound CO_2 which does not normally occur in an unoverloaded system in the presence of calcareous sand. If it does, however, more sand may be added, or sodium bicarbonate may be dissolved and administered with the distilled water through the float valve. Since the sand alone tends in a long-term sense to disproportionately increase the Ca in solution as compared with the Na, the occasional use of sodium bicarbonate, which tends to do the reverse, aids in keeping these two quantities in more nearly normal proportions. See Breder and Smith (1932).

The described procedures may seem to be somewhat complicated, but they are, in fact, not much more complex than those

involved in maintaining a similar number of standing fresh-water aquariums. After the equipment is built and regulated, so that valves and controls are in balance, there is nothing to be done with them at any time, and in fact there should be no tampering with them at all. It is probably wise to post warnings to this effect. There is little aquarium cleaning to be done, as most of the accumulating detritus is automatically deposited in the filters. Aside from feeding the fishes and sometimes cleaning algae off the glass sides, the latter being controlled by adjusting the lighting arrangements, there are the following routine matters to be done. These will vary with each installation but may be approximated by the regimen under which the described installation of seven aquariums were controlled, as follows:

		Minutes
Read pH and specific gravity.	Twice a week	5
Titrate sample	Once a week or less	15
Fill distilled-water carboy.	Twice a week	5
Clean filters	Once in 2 weeks	15
Make the adjustments based on above information.	Once a month or longer	Various

The need for changing the pump and motor is such a rare occurrence as not to figure in the above schedule and should not take more than 5 minutes. Every attempt has been made to reduce the maintenance of the system to its minimum. It is not uncommon for the system to be left alone for as long as 3 days, as over a long weekend. The only thing to normally expect at the end of this period is some extra-hungry fishes. It should be borne in mind that the smaller the system—that is, its total amount of water—the more rapidly decomposition or contamination can spread through it. It is prudent not to reduce the size of the equipment more than necessary.

ADDENDUM

Since this article was first published the following additional data have been obtained.

Control of inflow

Since stopcocks with Teflon, or similar, plugs have become available, it is possible to simplify greatly the construction of small float valves. As these newer type stopcocks are usually provided with rather heavy glass tubes, no special support is needed, the glass tube being quite strong enough to support the float with the tube fastened rigidly only at the inlet side.

The only modification necessary is the removal of the usually colored handle in the Teflon plug. This is easily forced out of the hole in which it rests. It is replaced by a suitably sized rod, such as that shown in text figures 2 and 3. This rod carries the float assembly and connects it with the valve plug. As these valve plugs are held in place by a Teflon nut, there is no need for modification or construction of a holding frame such as that shown in text figure 2. Incidentally, these plugs are not liable to stick, even after several years of service.

Constant-level siphon

The constant-level siphon illustrated in text figures 1 and 3 can be made virtually foolproof if the open end of the glass tee, which faces upward, is extended by a piece of flexible tubing. This piece should be bent over so as to form an inverted **U**, with its open end facing down, into the aquarium. This is most easily accomplished by providing a third hole in the supporting crosspiece. The open end should be placed slightly above the level of the outflowing water in the horizontal arm of the tee.

A siphon so arranged will prevent overflowing of the aquarium even if the incoming water is increased over a consid-

erable range. This is because, as the water rises, it occludes the open end of the down-facing tube. There is a slight negative pressure in this tube caused by the outflowing water in the constant-level part of the siphon. Thus, as the water rises in this accessory tube, the whole system becomes a simple siphon with two inlets, obliterating the constant-level feature. This increases the flow considerably, the amount being related to the length of drainpipe attached to the horizontal arm of the tee. The water level in the aquarium thus falls rapidly and the end of the inverted U tube is reexposed and the system regains its constant-level feature.

In practice, if the inflow of water to the aquarium is slightly more than the constant-level siphon will carry off, the water level in the aquarium will be at the mouth of the open tube. This tube will normally suck water from the surface and air, through a considerable range of inflow. Incidentally, this condition effectively removes any scum that may form on the surface.

The basis of this item was received from a correspondent shortly after the appearance of the 1957 issue of this paper. Unfortunately, the name of the individual concerned is no longer available, and it is therefore impossible to credit him properly here by name.

LITERATURE CITED

Breder, Charles M., Jr., and Thomas H. Howley.
1931. The chemical control of closed circulation systems of sea water in aquaria for tropical marine fishes. Zoologica [New York], Vol. 9, No. 11, pp. 403–442.

Breder, Charles M., Jr., and Homer W. Smith.
1932. On the use of sodium bicarbonate and calcium in the rectification of sea-water in aquaria. Journal of the Marine Biological Association of the United Kingdom, Vol. 18, No. 1, pp. 199–200.

Harvey, Hildebrande Wolfe.
1955. The chemistry and fertility of sea-waters. Cambridge University Press. viii+ 224 pp.

Sverdrup, H. U., Martin W. Johnson, and Richard H. Fleming.
1942. The oceans; their physics, chemistry, and general biology. Prentice-Hall, New York. 1087 pp.

Townsend, Charles Haskins.
1928. The public aquarium; its construction, equipment, and management. U.S. Bureau of Fisheries, Document 1045, Report of the U.S. Commissioner of Fisheries for 1928 (Appendix VII), pp. 249–337.

MARINE AQUARIUM PROCEDURES AND TECHNIQUES

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Abstract.—A closed-circuit system is used as the most dependable means of maintaining a balance of physical and chemical factors with a minimum of attention and maintenance. Several appliances as adjuncts to this system are discussed in detail, e.g., exhausting devices and capillary siphons which produce artificial tides. A special habitat for the breeding of intertidal animals in the laboratory, and a sand-bottom tank, designed from an esthetic point of view for public exhibition, are described.

Our present contribution to the aquarium sciences is concerned specifically with the field of experiment. The techniques that are already known, but which will be enhanced by details based on our experience, and the new, more important elements that make it possible to produce complex artificial environments will—we hope—be of service to the investigator as well as to those who maintain aquariums for exhibit purposes. The milieux that we have created for experimental uses have their place behind the scenes of a large public installation; they may also have their place amidst the tanks shown to visitors provided that they have been adapted and modified for that purpose.

DESCRIPTION

Being far away from the sea, we have been forced to use the same water over and over. It is not possible to obtain a biological equilibrium in an aquarium except by allowing the physicochemical factors as little variability as possible and, in any case, as is compatible with the survival of the population. The greater the volume of the water, the slower the changes occur and—in a general way—the easier it is to compensate for them. Moreover, a closed circuit with a large capacity is the most dependable means of keeping the desired balance.

There are several models of breeding installations that are adapted to the needs of marine biology. Most of them, including the one described here, have a reserve tank, a water circulation system, breeding tanks, and a filtering system.

RESERVE TANK

The reserve tank may consist of various materials but must have all of the following properties: Strength, water-tightness, and neutrality toward sea water.

A glass tank is relatively neutral but, unfortunately, is fragile. If it is large, stresses, changes of temperature, or vibrations may cause its destruction at any time.

If the tank is of concrete and well made, it has the advantage of being strong, but frequently it cannot be moved. Liquid that comes in contact with fresh concrete

This paper was prepared in French; it was translated into English by a commercial translating service.

undergoes a very strong alkaline reaction which makes the use of concrete impossible unless it is first treated. Generally, prolonged washing with fresh water is not sufficient, and frequent rinsing with sea water is impossible when the distance from the sea is great. The best technique consists in covering the cement with a neutral product: special paint, paraffin, plastic substances, etc. In our installations, paraffin has given the best results; it was heated and spread with a brush and afterwards impregnated by the flame of a blowtorch.

The lining of cement with plates of glass is a very good method for large installations. Finally, the application of plastic materials practically solves the problem. At this time, there exist ready-made tanks of 100 to 500 liters, of plastic that is absolutely nonreactive to sea water. This technique is excellent.

WATER CIRCULATION SYSTEM

Once the tank has been installed, it is essential that the breeding tanks, which are generally located at a considerably higher level, be supplied. At the present time, there are rotary pumps made of plastic which are immersed in the water and operated by a shaft which plunges into the water and is driven by an electric motor. This device makes it possible to supply a reserve tank which, by gravity, supplies the breeding tanks. It is preferable to any other device when a number of persons use the installation. When the reserve tank is full, it is sufficient to open the desired faucet when water in one or the other tank is needed. There is one difficulty, however: the pump cannot operate continously. It is therefore necessary to provide an electric regulator, and that introduces a possible cause of failure.

Exhausting devices

The system we have used is much less cumbersome; it is based on water lifts which operate by means of air pressure, viz., exhausting devices. These are vertical pipes immersed into the water of the reserve tank; their upper ends emerge in the form of swannecks in the highest tank of the installation. Air supplied by a small electric pump is conveyed into the tube at a sufficiently low level within the reserve tank to move the water in the tube and make it ascend into the upper tank.

Our experience has led us to the formulation of certain estimates which save much guesswork. The interior diameter of the main body of the exhausting device must measure close to 6 mm. The pipe may be rigid or flexible; it may be of glass, of vinyl, or of polyethylene. It may be straight or bent, but must not have the properties of a siphon.

The air duct must open into the tube in which the water ascends, below the level of the water of the reserve tank, and it must be moved closer to that water level as the height of the exhausting device above the reserve tank is increased (contrary to what one might be tempted to do). As a matter of fact, the thrust of the ascending air pulls a mass of air above the level of the reserve tank, and that mass of air tends to become smaller as the air arrives at a higher level. It is necessary for the operation of the apparatus that the water mass above the level of the reserve tank exercise a vertical downward pressure from above, which must be less than the upward thrust that the height of the water in the reserve tank applies to the lower part of the pipe. In figure 1 we see the exhausting device, represented by the pipe AOB. AO is the upper part and OB is the lower part of the device; $O'O''$ is the water level in the reserve tank. It is quite evident that the influx of air at C will drive a water column CO in the direction of A. The farther C is from O, i.e., from the water surface, the larger will be the column CO. As soon as this water column

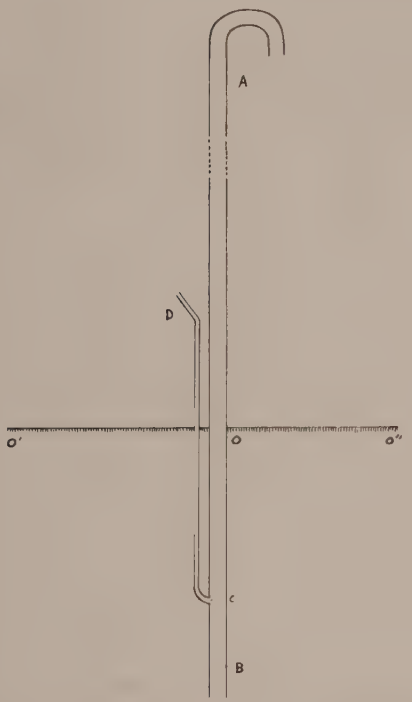

FIGURE 1.—General scheme of an exhausting device. Air arrives through tube *D* and ascends through tube *BA;* in doing so, it pulls water along with it.

starts moving, the water pulled along by the air bubbles joins it. The entire mass of water then exercises a downward pressure. The air which continues to reach *C* will be driven back toward *B*, and its pressure will increase until it reaches a maximum that is equal to the pressure exercised by a water column of the height *OB*. The device can function only when the pressure exercised in that way exceeds the thrust of the water mass contained in the part *CA*. In practice, an apparatus of this type is not used if it functions only with such intermissions as are due to the variations of the pressure at *C*. The height *OA* does not exceed two thirds of *OC*, and *CB* is very small.

It is advantageous to study the borderline cases; they have only a very weak output but are sometimes useful to know. A well-regulated apparatus, which works under the best conditions, has an output of more than 6 liters per hour. The necessary air pressure is a function of the height of the water *OB*. The pressure utilized under the most favorable conditions is theoretically slightly higher than the pressure of a water column of the height *OC*.

We have stressed the theoretical aspect of the problem of the exhausting device, since in practice the apparatus is susceptible of many variations in form, and since the conditions under which it is used and its perfection before use prevent a great many failures.

We have built most of our exhausting devices with glass tubing. A straight glass pipe 6 to 8 mm. in diameter ends at its lower part in a vinyl tube which is 10 to 15 cm. long and has an inside diameter large enough for the glass pipe to be inserted (fig. 2). Its bottom forms a strainer and is chamfered; it is perforated by small openings so as to prevent the deposition of sediments that may occur at any time. As near the glass pipe as possible, a hole has been made in the vinyl for the insertion of the end of the compressed-air pipe. This is a vinyl tube of small diameter. Plastic rings make it possible to keep it joined to the glass pipe for part of its length.

The upper end of the exhausting device is curved; it can be made in one piece extended and joined by a plastic ring.

BREEDING TANKS

In each one of our installations, the breeding tanks are made of molded glass. We have used several models the sizes of which correspond to the various populations.

Size of tank (length x width x height)	*Occupied by—*
15 x 10 x 15 cm	Scyphistomata, small groups of algae, Amphipoda, etc.
20 x 15 x 20 cm	Suitable for a very large number of animals of small size.
30 x 22 x 24 cm	Small Decapoda, mussels, Ophiuroidea, etc.
25 liters and above	Fishes, crabs, etc.

FIGURE 2.—Bottom of the exhausting device; it consists of a tube of plasticized vinyl. Its lower part is chamfered and perforated by little holes. *A*, air inlet.

Today's techniques make it possible to build tanks of transparent plastic materials. The main advantage is the possibility of having tanks built according to the model chosen, and of fixing water inlets and outlets without the need for any siphons. The fragility of these tanks is usually rather great, particularly in the large sizes. They must be well constructed so as to prevent the pressure of the water from tearing the seams of the walls apart.

Tanks with metal corners have the great advantage of being able to be built in large sizes. The metal must be particularly carefully insulated so as to prevent it from being attacked by the sea water. The plastic or bituminous linings that may be used are evidently unsuitable for physicochemical investigations of the water.

There are tanks of 100 to 200 liters' capacity, the frameworks of which are of fiber or cement covered with plastic. The only real inconvenience is the size of the framework.

In summary, in a particularly detailed study where the chemical elements have been specially studied, it is preferable to use only glass or plastic material.

Water supply to the breeding tanks is by means of a cascade arrangement. An upper tank receives the water from the reserve tank through an exhausting device or through a pump, and the excess flows into a tank located at a lower level, and so forth, down to the lowest one, which generally empties itself into the reserve tank by means of a filter.

Whenever the arrangement of a tank makes it possible, we have attempted to establish a cross circulation in such a way that the entire water mass is renewed. When there are only very small animals or plants, and when the current of the water is weak, the water may very well pass from the inlet to the outlet without renewing the contents of a tank. In that case, calm zones come into existence where the physicochemical conditions of the milieu may be very different from those prevalent within the current of the water. We may cause the water to arrive from the tank at an angle and at the bottom, while we

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cause it to leave at the opposite angle and at the top. If the current is sufficiently strong, and if the form of the tank is adequate, then a rapid test performed with a few milliliters of colored water—e.g., by the addition of a few drops of a neutral red or any other nontoxic coloring substance—will enable us to find some eddies, the localization of which can be most useful in a breeding tank.

Of the measures required to keep the water supplied with oxygen in the different tanks of a series, we have demonstrated a reduction of that oxygen which progresses from the exhausting device to the lowest tank. To remedy that shortage, we have arranged the tanks, not in a parallel series, but in the shape of a fan; this has enabled us to use progressively larger tanks. Accordingly, in the first tier each tank receives the water from one exhausting device. For example, four tanks receive each the water of one exhausting device. The second tier comprises only two tanks, of a larger size. Each tank receives the water of two higher tanks, that is, of two exhausting devices. The third tier comprises only one large tank which receives the water of the two intermediate tanks, that is, of four exhausting devices.

This distribution affords greater safety to the overall installation. As a matter of fact, if one exhausting device stops operating for one reason or another, only one single tank will not be fed any longer; the tank of the second tier that is branched upon it will still receive the water of the exhausting device of the neighboring tank while the tank of the third tier will receive the water of three exhausting devices. Finally, it is possible to double the number of exhausting devices and to feed them by means of two pumps both of which are branched upon all the tanks.

Connections between tanks—the siphons

When plastic tanks are used, it is very easy to make an overflow pipe by perforating the wall of the tank and attaching to it a plastic or glass tube. In the latter case, it is preferable to solder it. Any wood or rubber connections should be avoided. The former are easily gnawed by animals—sea urchins, gastropods, etc.—while the latter are frequently attacked by the sea water. It is easy to secure plugs of plasticized polyvinyl chloride; they remain flexible and are not attacked by sea water. (Note well: some polyvinyl products are not neutral in sea water.)

When the breeding tanks are made of glass (our installation is of this type), the perforating of the walls is always a delicate operation. The use of siphons makes this operation unnecessary. Over a period of several years, we have used two types of siphons which have been entirely satisfactory:

1. *Permanent siphons.* — Generally speaking, the siphons will not run dry as long as the inlets and outlets remain in the water. In the siphon shown in figure 3, the inlet *A* is maintained constantly within the water by means of the mounted swanneck *C* which connects directly with the outlet of the siphon. An inlet for air has been created at *E* to simplify priming the siphon between *B* and *D*. On the other hand, that air inlet makes it possible to prime the first siphon by aspiration through that opening with the aid of a flexible tube. The water arrives through *A* and *F*, filling the tube. When the flexible tube is withdrawn, the part *CD* will dry up by itself, and the apparatus will be in operating condition. When the end *F* does not reach into the water of the lower tank, it is necessary to plug it during the priming operation.

We have equipped the inlet of certain siphons with a sort of funnel, the opening of which is covered by a nylon screen that

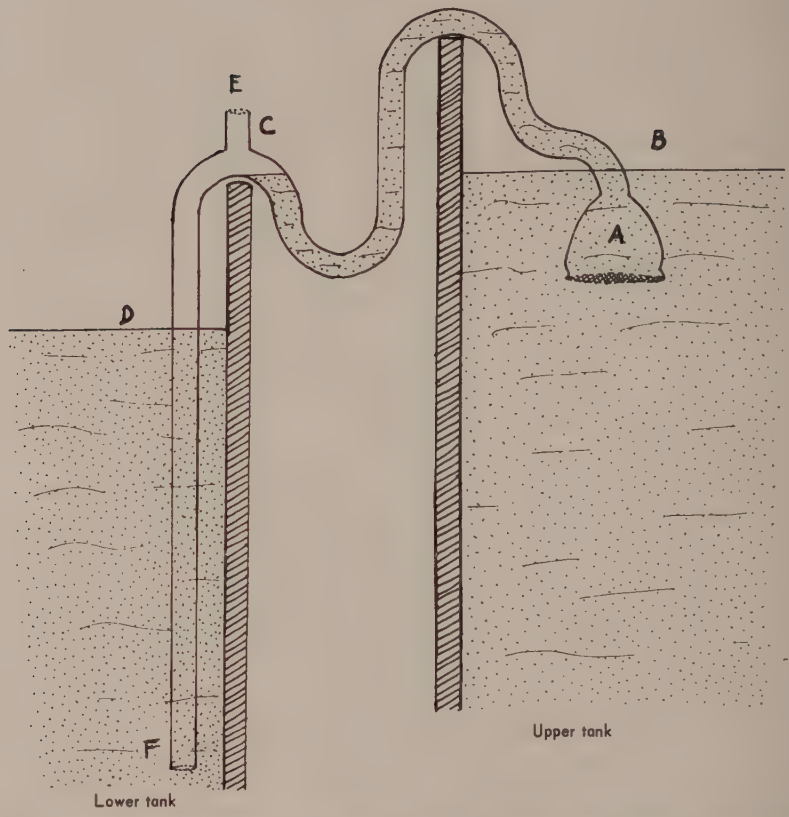

FIGURE 3.—Type of permanent siphon; *A*, flared opening of the siphon, capable of accommodating a screen; *1*, upper tank; *2*, lower tank; *E*, air opening.

is fixed there by means of a vinyl ring. This has enabled us to separate, from one tank to another, very small animals which, without that precaution, would have passed through the siphons. These funnels are preferably positioned in such a way that their opening is at the bottom end and as far away as possible from the walls of the tank so as to reduce the risk of the deposition of sediments.

The level of the upper tank is regulated by the height of the swanneck *C*; the level of the lower tank is determined by its outlet siphon which does not appear in the drawing.

It is helpful to have a supply of siphons of this type. In order to clean them, it is sufficient to place them, from time to time, in a hypochlorite solution to soak, and to rinse them well before use. When the siphons do not have screens, a sulphochromic mixture is preferable.

2. *Capillary-priming siphons.*—We have perfected a siphon the curved part of which is so narrow that capillarity may be able to prime the system even before the water reaches the point of overflowing (figs. 4, 5, 6, and 7). By duplicating our piping system of permanent siphons with

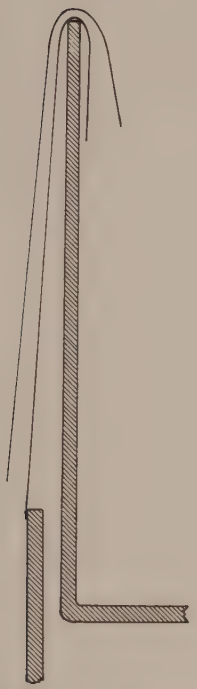

FIGURE 4.—Theoretical section of a capillary priming siphon flaring at both ends.

FIGURE 5.—Simple siphon, poorly made (lower part is too big). It is essential that the lower part of the siphon is not immersed into the water.

these capillary siphons, we have put into effect a very simple and highly efficient safety device. In order for such a siphon to be able to begin its priming action, it is essential that its lower end does not reach into the water, so that the water of the upper tank may ascend freely in the tube, and that—aided by capillarity—the water may reach the highest point of the curvature before the water level in the upper tank goes past the edges. When a system of this type operates within a tank, it introduces continuous variations of the water level into it, provided, however, that the supply to the tank is much smaller than the output of the siphon, and that the inlet of the siphon has a much larger diameter than its curvature.

We have also used a siphon the upper part of which is capillary; in that case, the siphon no longer exercises practically its priming action, and the water level in the upper tank remains constant. Capillarity keeps a small quantity of water in the tube of the siphon; when the supply to the tank becomes weaker than the output of the tube, this water breaks up into short water columns whose distance one from another becomes greater as the water supply in the siphon becomes weaker. This siphon practically never runs dry.

In these siphons, the current of the water is strong, and the organisms, particularly the Diatoma, attach themselves less rapidly there than on the permanent siphons where the current is weak. But inasmuch as they serve as a subsidiary canalization, the pipes are normally not operating, so their maintenance is limited to cleaning them after an occasional oper-

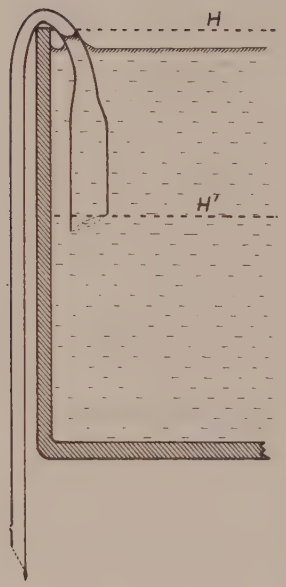

FIGURE 6.—Intermittent siphon with capillary priming, well made: *H* and *H'* represent the range of the "tides."

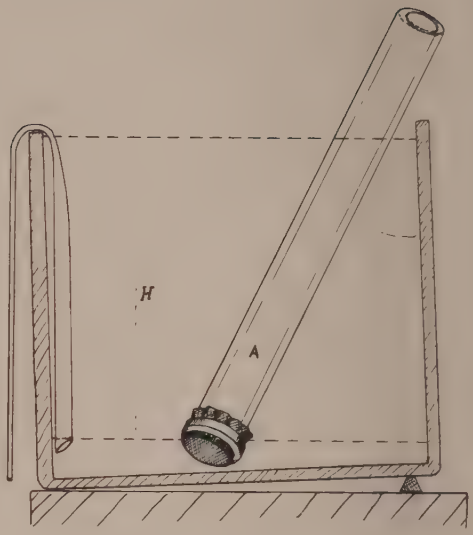

FIGURE 7.—Scheme of a breeding tank for very small animals: *H*, range of "tides"; *A*, tube into which the little animals are placed.

ation. Consequently, they are always ready for use.

On the other hand, the establishment of a siphon for capillary priming is not very easy, and the satisfactory operation of the system is dependent on a certain number of favorable elements:

1. The curvature of the siphon must be smaller in the downward direction than in the upward direction. The diameter of the tube must be slightly smaller at the highest point so as to facilitate the priming. Any other arrangement will adversely affect the satisfactory operation of the system.

2. The bottom of the siphon must be made in such a way that there will be no hanging drops. A hanging drop would act as a plug and prevent the water from ascending, by capillary action, into the upper part of the system. We have therefore attached, at the outlet of the siphon, either a flare designed to prevent the hanging drop, or a chamfered "glass drop" at the end of the tube, which serves the same purpose.

3. The tube must be made of glass that can be wetted, and not of plastic. Sometimes it happens that after a prolonged use the tube remains dry for some time. In that case, it is almost always necessary to "wet" it in order to put it back into operation. A washing with a sulphochromic mixture is then required to make it as good as new.

The diameter of the tube, at its narrowest part, may vary on a wide scale, but it must be sufficiently large to enable a water current to drive the air out of the lower part of the siphon when the siphon is formed by a tube which has an interior diameter of 6 mm. and is tapered in the curvature. When the siphon is formed by a small tube having an interior diameter of 3 mm., the curvature need not be tapered, but in this case the lower part of the siphon must be elaborated most carefully

so as to avoid the formation of hanging drops, since this last-mentioned system, while it rarely dries up, also cannot be put back into priming action as readily as the preceding system.

We have come to the point where we prefer to use the first type of capillary system, which dries up frequently and can be put back into priming action easily, in order to create "tides" in small glass tanks. This arrangement has enabled us to succeed with breedings which would have been difficult to achieve under other conditions. When the feeding of the tank "in the tidal way" in this manner is of too large a volume to have the tank emptied by a capillary siphon, we have been using a complex system in which the capillary siphon primes one or more simple siphons. This type of apparatus is rather difficult to build—if not to conceive—but once it has been completed, it is able to operate for a very long time without any surveillance. The simple capillary siphon, for tides, must have a very large inlet so as to dry up abruptly at the end of the operation, when the air is swallowed up into the tube, owing to the lowering of the water level in the upper tank.

Utilization of the "tides"

It must be mentioned at the outset that these artificial "tides" are only very distant relatives of the true tides which, from the biological point of view, are rather complex phenomena (currents and inversion of currents, change from an agitated to a calm phase, variations of the turbidity of the water, of its temperature, salt contents, luminosity, etc.).

The use of capillary siphons to create "tides" is not limited to the breeding of animals which one wants to flush out periodically. We shall now briefly review the uses to which we have put them, but it is possible to think of many other applications:

1. It is not always easy to breed small animals when it is desired to confine them within a restricted area for "boarders" (temporary occupants) which, at the same time, require very frequent changes of water. Into a "tidal" tank, tubes that are open at both ends may be placed vertically. As the water level is variable—from the bottom of the tube to its upper end—the volume of the water that passes into that tube during any given period is proportionate to the number of tides that have taken place during the same period. If it is desired to breed animals in these tubes, it is sufficient to block the ends by a nylon screen. In that way, the animals can be isolated easily, they are able to have enough water, and the breeding is limited to a very small area. In practice, the breeding tubes are assembled into bundles, and only their lower end is immersed into the "tidal" tank (fig. 7).

2. For breeding of animals within the upper limit of the tides (fig. 8), a tank (*A*) receives water from the exhausting device through a large pipe which descends to the bottom of the tank. A bed of gravel has been placed on that bottom; it is covered with a screen and with sand—an arrangement that is similar to the sand tank which we shall discuss later. The breeding tank proper (*B*) has been placed on the bottom of the sand layer; this tank consists of a glass cylinder which is closed, at its upper end, by a removable sheet of glass (*F*). Pebbles collected on the seashore have been placed inside the cylinder on a layer of sand the thickness of which varies but must be such that its level is very considerably lower than level *1*.

The level of the water in tank *A* varies between *1* and *2*, because of the siphon *C*. The water ascends and descends in cylinder *B;* it wets part of the pebbles which, therefore, retain a high humidity. The water in cylinder *B* acts amidst the pebbles like a piston, in such a manner that

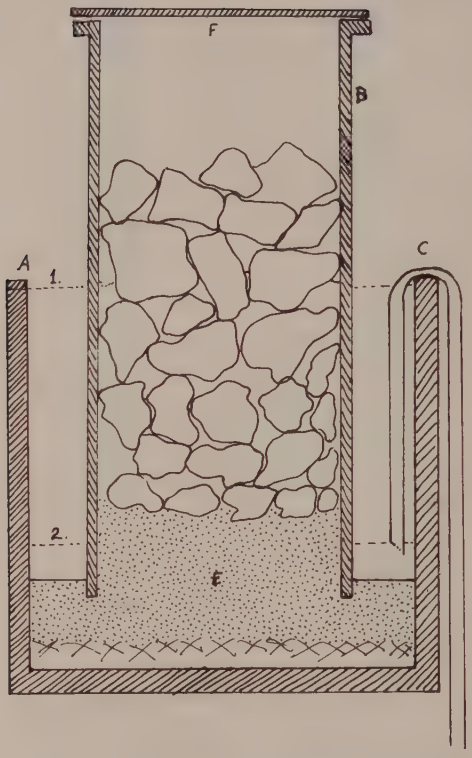

FIGURE 8.—The "tidal" tank (*A*) into which is immersed the bottomless tank (*B*) which rests on the sand (*E*). A plate of glass (*F*) covers the upper part. The air enters and leaves at the cover (*F*) without having to pass the small breeding animals. Since the saturated atmosphere is not suitable for some animals, it is sometimes necessary to replace the cover (*F*) with a fine screen, but in this case the pebbles of the upper zone are quickly covered with salt precipitations. *C* is an intermittent capillary siphon.

the air passes, without stopping, the edges of the cover *F* which has been simply laid upon the cylinder. In that way, the air in the breeding area is constantly renewed. It is advisable to provide a sufficient height so that the upper level of the pebbles will be relatively dry. It is also possible to replace the glass plate *F* by a fine screen.

3. We have also made use of the "tidal" tank whenever a breeding situation required good irrigation while the topography of the breeding tank did not afford it. Thus, when the accumulation of substances of all kinds in a tank is such that the circulation is poor, it is very useful to have recourse to this technique which makes it possible to renew the water, in its totality and everywhere, with every tide.

The substratum

Generally speaking, the breeding tank does not require any special substratum, and the glass or plastic wall of the tank itself constitutes the breeding ground.

If it is desired to provide rock animals with a suitable substratum, an adequate piece of rock is placed in the tank; generally, this presents no difficulties. Such, however, is not always the case when it is desired to introduce a sandy or muddy bottom.

An anaerobic milieu develops very rapidly under the first millimeters of the ground; it immediately begins to discharge hydrogen sulphide which may cause the death of the animals and plants to be bred. We have introduced a very simple solution to this problem.

Quantities of oxygen that were dissolved in the interstitial water of the coastal sand have shown us repeatedly that the partial oxygen pressure is weak: approximately 30 to 40 percent of saturation. In certain cases, the oxygen pressure is practically nil. These facts can be explained easily: the oxygen contained in the interstitial water of the sand has its origin in the irrigation of that sediment. When the sand is subject to the swing of the tides, its level also is subject to variations that bring about a circulation of the water. It is a matter of course that this level, for a certain amplitude of the tides, is subject to variations which increase as the elements of that amplitude become

rougher. Another intervening factor is the action of the fauna which modifies the permeability of the ground by burrowing corridors. The fauna which consumes oxygen favors the circulation of water in the submerged sand. These considerations have permitted us to use substrata of sand of considerable thickness, capable of accommodating a rich fauna. We have built this tank with the thought in mind that an adaptation period is required during which the fauna and the flora become settled and establish a certain equilibrium; thereafter, the artificial balancing mechanism (water current, etc.) can be reduced considerably, without any important change of the biotope.

The scheme of an experimental sand tank is shown in figure 9. The water comes in at *1*, through the large vertical pipe which is open at *2* and *3*. The water reaches the bottom of the tank directly, flows freely between the pebbles and the various shells, passes through a nylon or fiberglass screen and filters through the sand layer *6*. The sheet of water *7* flows off through the siphon *8*.

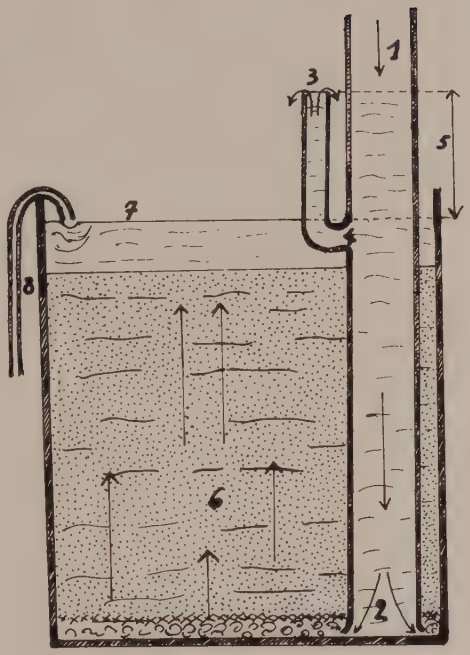

FIGURE 9.—Scheme of a sand tank: *5*, height of the water determining the pressure required for irrigation of the sand.

The volume of water which arrives at *1* does not flow off easily through the sand layer. When the water level in the large pipe rises the pressure in that pipe increases. That pressure must not be too high because the water would immediately pour forth violently from the sand, in the form of a "spring." It is easy to determine the optimum pressure. In practice, the height of the water column above the level of the tank (*5*) must amount to approximately one-fourth the depth of the sand. It is possible to make an opening of any size in the large pipe, preferably at that level. This is what we have done in the case of the usual breeding tanks. We have now begun, however, to make experimental tanks that have an opening *4* at a lower level than that of the water in the aquarium. To that opening, we have attached a bent tube which is open at *3*. By making that tube rotate around *4*, the opening *3* may now be brought to the level desired. By means of devices of this type we obtained our first data concerning the equilibrium of aquariums with sand bottoms. When the tank has operated in that way for a certain time, the sediment settles somewhat, the bottom becomes clogged, and the amount of water that will effectively pass through the sand on its way from the large pipe is reduced gradually. One may then remove the bent tube and, thereby, suppress almost completely the irrigation coming from the large pipe. The irrigation of the sand will then continue to be taken care of almost exclusively by the fauna that has been installed in the sandy substratum, and no symptoms of anaerobiosis will appear.

During the numerous tests which we made we had never made a lateral opening in the large pipe. We noticed, then, an inconvenience of rather secondary importance when this mode of procedure is adopted: the inflow of the water which most frequently is handled by means of an exhausting device causes precipitations of water that we later have tried to prevent. Nevertheless, one of our installations has made use of that very phenomenon to create a "spindrift zone."

The tanks with mud bottoms are conceived along the same lines as those having sand bottoms. It must be noted, however, that the irrigation of the mud by means of the water column of the large pipe is extremely weak. Almost all of the water passes through the overflow pipe of the large tube. Too strong a pressure on the mud must be avoided because the mud is much less resistant to the "spring" phenomenon than the sand. As to the surface, it is particularly important to study the water current so as to prevent its scooping out the mud. Finally, when building a tank of this type, it is advisable to provide, between the screen at the bottom of the tank and the mud, a layer of a few centimeters of sand.

FILTERING SYSTEM

The tanks with sand bottoms may be located at any point within the closed circuit of an aquarium. They may be mounted in series or parallel. It may be well to note that they act as complete or partial filters, and for that reason they should be intercalated at suitable points in the circuit. We have used these tanks as filters in several different circuits. They do not need any frequent maintenance operations and are able to go on for years. Generally, they act as partial filters, and the problem of complete filtration will have to be solved many times without them. We have not used any permanent filters but have been content with sand-bottom tanks acting as partial filters since—in a complex breeding installation where we have been more interested in bringing about a biological equilibrium than in the survival of a certain species—such a filter traps the plankton and we generally were eager to avoid such a trap. But in a breeding installation where microfauna and microflora are suspended in the water and constitute a true plankton, it is sometimes necessary to introduce a complete filter into the circuit in order to restore an equilibrium that has been upset by an intervention of an experimental nature. For that purpose, we have used a large-dimension Pyrex glass tube, having a diameter of 110 to 120 mm., and a length of 80 cm. It was placed vertically into the reserve tank where it exceeded the water level by 30 to 40 cm. Its lower part is closed by a plug of polyvinyl chloride which is perforated and is kept in position by plastic tubes that are reinforced internally by metal rods. These reinforced tubes are held at the upper part of the Pyrex tube by their ends which have the form of hooks. We introduced empty shells into the filter, at its bottom, in a layer having a thickness of 5 cm., followed by a nylon screen which holds a 20-cm. column of charcoal; this is followed by a thin layer of glass wool covered by small pebbles in a thickness of 15 to 20 cm. This filter is kept in place during the time required and is maintained at a suitable level.

MODIFICATION OF THE SAND MILIEU FOR A PUBLIC TANK

The installation with a sand bottom that has been described may be of great interest in a public aquarium for the presentation of psammophile anemones, pleuronectids, sand crabs, etc. In large sizes, this apparatus can be installed with two lateral

edges that recede according to Garnaud's principle of the tank with nonparallel sides, and with plate glass inclined at about 20° from the vertical so as to show the sand bottom at a convenient angle. The back of the tank (the part opposite the glass) will be strongly concave and very much bell-mouthed. In this section, the wall will be inclined at about 45°. Under these conditions, an observer looking through the glass will not see the lateral edges; he will practically not see the water surface, and he will easily confuse the back and the floor.

The principle of the aquarium with nonparallel sides according to Garnaud has one fault: it presents to the public an exhibit area that is relatively small as compared with the size of the tank, and if the exhibit is particularly attractive the visitors will crowd each other in front of the aquarium. Consequently, we suggest an entirely new form in which two sides are slanted parallelepipeds that enable the visitors to see the exhibit clearly from two angles. The advantage in servicing the aquarium is certain: despite the large size of the tanks, they have very little depth (fig. 10, 11, and 12).

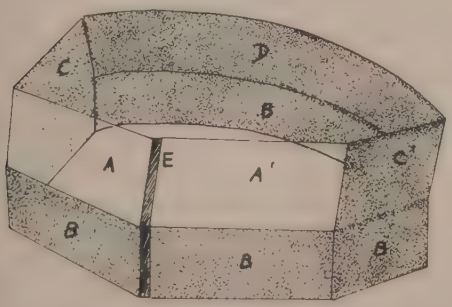

FIGURE 10.—Sand tank for public exhibit. The heavily stippled areas represent the blind sides of the tank. Sand fills the lower section (*B*) of the entire tank, up to the bottom edge of the plate glass (*A* and *A'*). The back of the tank (*D*) slopes backward in order to blend visually into the sandy soil bottom. *E* is the channeled corner holding the plate glass.

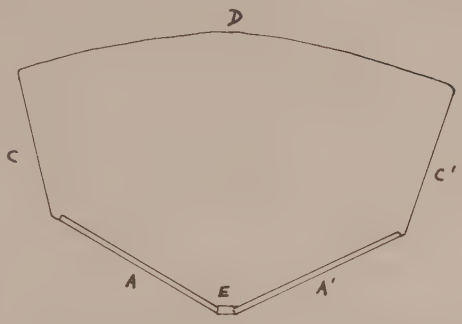

FIGURE 11.—Bird's-eye view of sand tank for public exhibit, showing 5-sided shape of tank.

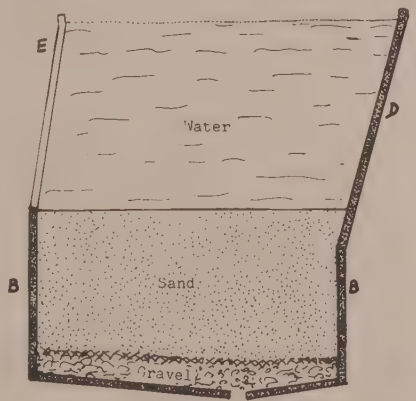

FIGURE 12.—Cross section through the middle of the sand tank, from *E* at center front to *D* at back.

An aquarium of this type, in which the length of the two panes of glass reaches 2 m. while its total length amounts to 2.50 m. and its width is 1.60 m., affords a field of view that appears to be unlimited. In this example, the height of the free water would certainly not exceed 1 m.

Cultivation of algae

This arrangement is very efficient for cultivating marine algae, either for particular studies or for maintaining an isolated marine environment in perfect equilibrium (figs. 13 and 14).

We have developed a technique of culture upon a film of water. Under these

conditions the gaseous exchanges between the air and water attain their maximum activity. Most of the algae spread out and assume strange forms; *Codium tomentosum*, for example, develops a thick knobby cover. This technique for cultivation of algae raised on glass, commercially known in France by the name of "lessive," permits the complete isolation of volumes of air which are important for raising aerobic marine invertebrates separately upon a blanket of *Codium* sp.

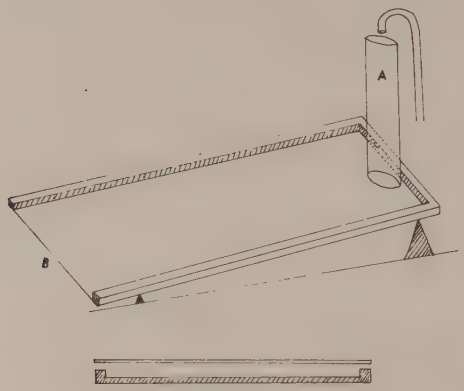

FIGURE 13.—General plan of equipment for cultivation of algae: *A*, inlet of water; *B*, outlet of water. The general plan without the top plate is shown at top; a cross section showing the top plate is at the bottom.

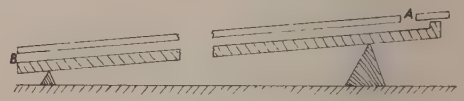

FIGURE 14.—Cut-away section of algae-cultivation equipment: *A*, inlet of water; *B*, outlet of water.

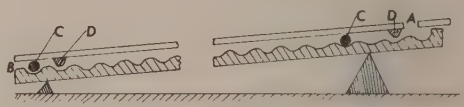

FIGURE 15.—Cut-away section of a plate of the "lessive" type: *A*, inlet of water; *B*, outlet of water; *C*, glass rod for breaking up the flow of water; *D*, bar of glass fastened to the top plate for breaking up the flow of water.

CONCLUSION

We have acquired our experience in "aquariology" by looking for special solutions to problems of experimental ecology. The rules that we have worked out gradually will perhaps enable others to save a good deal of guesswork. The actual establishment of special habitats is even now most helpful in the field of experimental investigations.

The needs of the public aquarium are different from those of a research aquarium where the care for the living conditions of the occupants is not combined with esthetic preoccupations. Many of the techniques described here have been conceived for the purposes of experimental ecology and cannot be transposed directly; on the other hand, the aquarium with a sand bottom—presented in a tank with nonparallel sides and with inclined glass—is certainly a fortunate transposition from the experimental scale to the large-scale public presentation.

A FAST-FLOW CLOSED-CIRCUIT MARINE AQUARIUM

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Abstract.—A relatively fast flow of sea water results in a much greater success in keping marine organisms in aquariums, and a closed-circuit system will remain biologically balanced without changing or filtering the sea water and without temperature control. The water is actively circulated by a special pump which is an elaboration of the bubbling tube. This pump has advantages over conventional pumps in the absence of corrosion and contamination and of damage to organisms passing through it; it requires little maintenance.

In earlier papers (Hale, 1957, 1960a) I briefly described closed-circuit experimental aquariums which probably owed their success primarily to the relatively fast circulation of the sea-water. There were neither filters nor reserve tanks in the system; the water was never changed nor its temperature controlled. From the experience so gained a permanent apparatus was built and has been operated successfully for over 4 years. The details of this aquarium are described in this paper.

ECOLOGICAL CONSIDERATIONS

The essential features of this aquarium are based on possible changes in the aquarium water, and how these changes might be counteracted by providing an adequate flow of water. These considerations will be discussed briefly.

Inorganic ions

The greatest problems encountered with sea-water aquariums arise from changes in the concentration of ions which occur in the artificial environment. These changes are caused by the contained organisms, and any radical departure from normal is likely to be detrimental. Important among these ions is calcium. The concentration of this ion is likely to be rapidly reduced by the many organisms processing calcareous skeletons; they actively remove calcium from the sea water (Bevelander, 1952; Robertson, 1941; Wilbur and Jodrey, 1952). A decrease in the calcium ion concentration might also take place if the carbon dioxide tension were reduced by too much photosynthesis (Harvey, 1957), and also if the sulphate ion concentration rose as a result of aerobic putrefaction of excessive protein sulphur from dead organisms. Replacement of calcium is likely to take place if an excess of calcium carbonate is kept in the water, such as mollusk shells or limestone chips. It is also clearly an advantage for the pH of the sea water to be kept normal (8.1–8.2) by providing light for an adequate degree of photosynthesis. Photosynthetic plants are also desirable to control inorganic nitrogen.

The concentration of ions containing nitrogen is likely to increase considerably over the minute amounts contained in the sea (Oliver, 1957). Ammonia is excreted by many marine animals; the excretory urea of some will be rapidly hydrolyzed to ammonia. Ammonia is oxidized by nitrifying bacteria to nitrite and then to

nitrate. It will accumulate as nitrate unless removed by photosynthetic plants.

Other major constituents of sea water are unlikely to alter significantly, but the concentration of some minor constituents may do so. For example, phosphate is removed by plants and some animals, and excreted by animals but information on this ion is too meager to make a useful assessment of the situation in an aquarium. Other ions, such as iodide, silicon, and copper, may become depleted when particular organisms requiring them are kept in the tanks.

Suspended particles

Marine bacteria are largely sedentary (ZoBell and Anderson, 1936); nitrifying bacteria are found associated with suspended particles. These particles may adsorb ammonia (Cooper, 1948a), thereby encouraging bacterial oxidation.

Most of the iron in the sea occurs as colloidal particles (Cooper, 1948b; Cooper, 1948c; Harvey, 1937b). Nitrifying bacteria require iron (Spencer, 1956), as also do diatoms (Goldberg, 1952; Harvey, 1937a) which are useful photosynthetic organisms in an aquarium. Suspended particles are essential as food for filter-feeding organisms. Thus suspended particles are an important feature of the marine environment, and the common practice of filtering aquarium water would appear to be harmful.

Water movement

The necessity for an active movement of water in an aquarium is indicated by the fact that the majority of organisms kept therein are relatively sluggish or sedentary. The materials they require for their existence which are contained in the water, and the desirability of flushing away excretory products, must therefore be mediated by the water. Marine organisms fall into three main groups as regards these materials. Firstly, there are the animals and the aerobic putrefying bacteria; they require oxygen, and their waste products include carbon dioxide, ammonia, and some inorganic phosphate and sulphate. Secondly, there are the nitrifying bacteria requiring oxygen, ammonia, and phosphate, and producing carbon dioxide and, ultimately, nitrate. Thirdly, there are the photosynthetic plants which, in the presence of light, more importantly require inorganic nitrogen, phosphorus, sulphur, and carbon dioxide; they give off oxygen. Thus the requirements of one group are the waste products of another, and a stream of water is the obvious means of transportation of these materials.

To this must be added the function of a moving stream of water in supporting suspended particles.

There may be other beneficial properties of an active water movement. For example, marine hydroids become moribund and die in 1 or 2 days in stagnant water, but they will live indefinitely in a moving stream of sea water (Hale, 1960a, 1960b). The reasons for this remain obscure.

In the aquarium here a rate of flow of water of 10 feet per minute is maintained and is generally satisfactory. Faster and slower rates are found in different parts of a tank. The flow may be increased considerably by the use of baffles.

Temperature

Consideration of the literature on the temperature tolerance of marine organisms indicates that a temperature up to at least 20°C. is not harmful to organisms from temperate seas. The water temperature in the aquarium here has risen to 21° C. without noticeable effect on the contained organisms.

DESIGN OF AQUARIUM

This brief survey of aquarium conditions points to a simplicity in the design

of aquariums in that filter beds, temperature control, and large stocks of sea water (an important consideration to laboratories remote from the sea) are unnecessary. The degree of success of the aquarium here supports this conclusion. The tanks in this aquarium are arranged in series with a specially designed water-circulating pump placed between two tanks in the circuit. Thus the sea water passes from the pump through one tank after another and back to the pump again as a continuous circulation of the same water. The pump and tanks are designed so as to maintain an adequate flow of water; all parts of the apparatus in contact with the sea water are of glass or plastic. There is a device for producing tides, technically easy in a closed system, and lighting is provided for some tanks.

The pump

The desirable features of a sea-water pump are that it should not corrode in sea water nor should it have moving parts in the water. Corrosion shortens the life and reduces the efficiency of the pump. Metals (except perhaps stainless steel) may corrode and liberate ions toxic to marine organisms. Moving parts are exposed to abrasion by sand grains and may damage organisms passing through them. To overcome these difficulties the pump I have used is an elaboration of the well-known bubbling tube, and is fashioned in plastics. A bubbling tube consists of a vertical tube into the bottom of which air is pumped; the bubbles rise to the top carrying water with them. The efficiency of such a tube depends on its length and bore, the rate of air injection, and the head of water against which it pumps. Figure 1 shows that a tube of about ½-inch bore with a low rate of air injection is the most efficient. More water may be pumped by increasing the rate of air injection, but the efficiency of the tube decreases. The

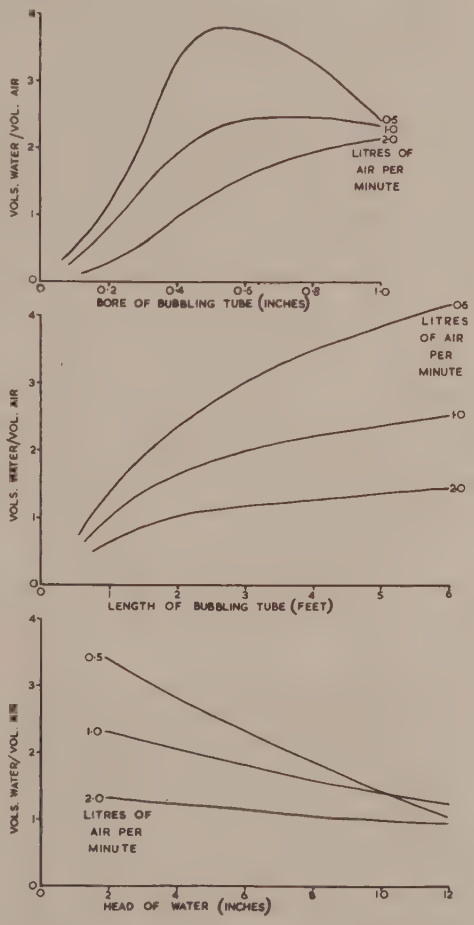

FIGURE 1.—Efficiency of bubbling tubes (volume of water per volume of air) at stated rates of air injection. At top, effect of the bore of a tube (5-foot length, no head of water); in the middle, effect of the length of a tube (½-inch bore, no head of water); at bottom, effect of the head of water (5-foot length, ½-inch bore).

efficiency of a bubbling tube also increases if its length is increased. It decreases in efficiency as the head of water against which it pumps increases; this is not a serious objection for closed-circuit aquariums, as the head of water is never more than a few inches.

The pump I use here is provided with 12 bubbling tubes of ½-inch bore. The base of the pump (figs. 2 and 3) is fashioned of Perspex. Water from the 'last' tank is led to the central 2-inch-diameter water inlet by a polythene tube from a similar adapter attached to this tank (fig. 4). The water then passes out into the ring of bubbling tubes. These are of PVC (polyvinyl chloride) and carry the water, plus air bubbles, through an adapter (fig. 4) to the 'first' tank. Air is injected into the bases of the bubbling tubes through the outer ring of nozzles; the size of the air orifice has no effect on the efficiency of the bubbling tube.

Each air inlet must have its own control valve. In the present equipment, air from a compressor passes into a Perspex chamber provided with 12 air outlets, each having a simple Perspex valve. It is possible that a simpler design would be to fit these valves to the basal part of the pump. The required pressure of air is that which is sufficient to overcome the pressure of the column of water in a bubbling tube (for example, ⅕ atmosphere for a 6-foot tube).

When working at an economical rate this pump moves about 250 gallons of water per hour (300 U.S. gallons) for the expenditure of about 12½ cubic feet of air. Increasing the rate of air injection increases the rate of pumping water but is less efficient; 25 and 50 cubic feet of air will move respectively about 310 and 375

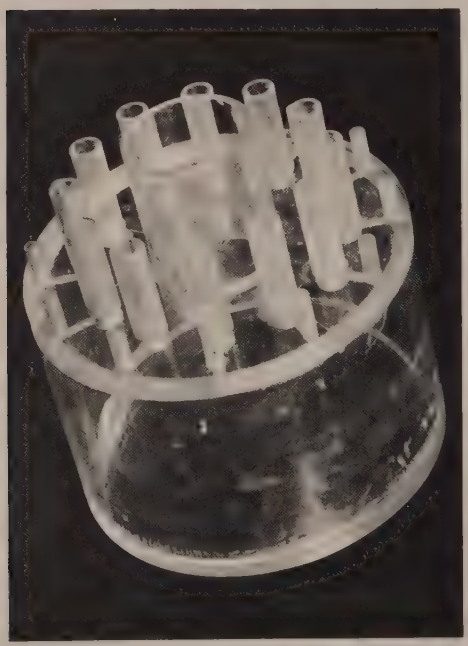

FIGURE 2.—Pump base, made of Perspex, with 12 PVC bubbling tubes of ½-inch bore.

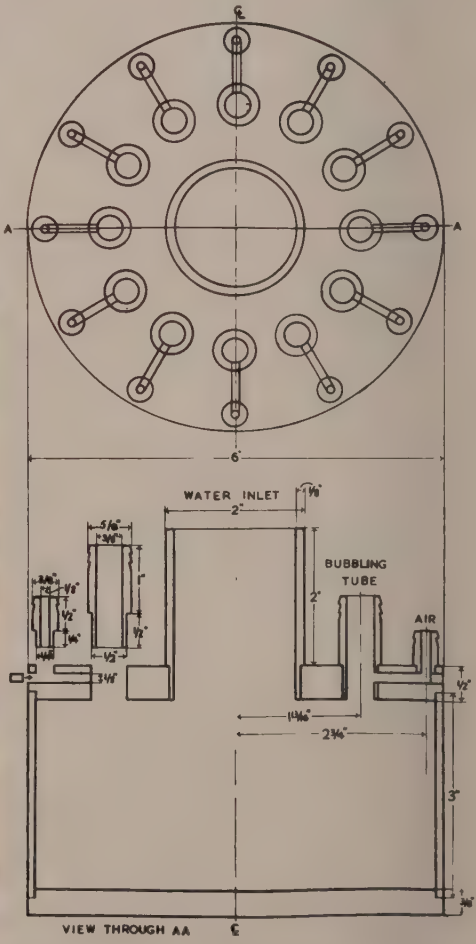

FIGURE 3.—Plan and section of pump base.

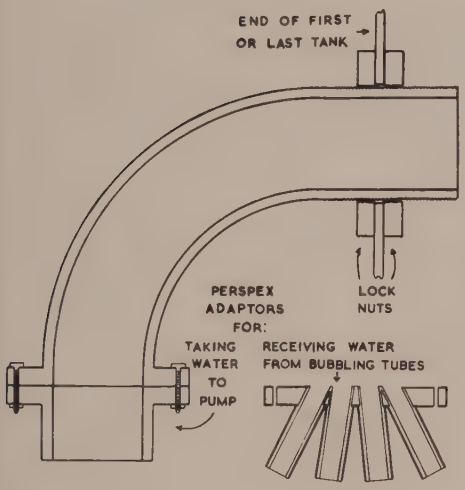

FIGURE 4.—Units for taking water to and from the pump. They are of black Alkathene except for the adapters which are Perspex.

gallons of water per hour (370 and 450 U.S. gallons).

This pump has run without fault for over 4 years; its only maintenance is an occasional cleaning (about twice a year).

It should be noted that the pump also aerates the water.

The tanks

The tanks are of normal construction with angle-iron frames and glass fronts, backs, and bases. The one unusual feature is that the ends are of Perspex. Perspex has advantages over glass in that the hole for the connecting units is more easily made and its greater resilience allows for small expansions and contractions due to temperature changes.

The glazing cement is made by mixing, as dry components (proportions by weight), 3 parts litharge, 3 parts silver sand, 3 parts of plaster of paris, and 1 part powdered resin, and then adding enough linseed oil to make it of puttylike consistency. It takes a few days to harden.

This cement is inexpensive but not altogether satisfactory as it tends to become rather brittle in time. In normal use it is quite sound, but careless handling or jolting of tanks might cause it to crack and cause a leak.

As is well known, iron frames need very careful and thorough painting to prevent corrosion. Normal oil-bound paint has been used here, but renovation has been necessary every year or two. Epoxy-resin paints would be well worth trying and are likely to resist corrosion much better.

The dimensions of the tanks and the position and bore of the inlet pipes are of some importance in relation to the maintenance of an adequate rate of water flow. The tanks here are 3 feet long, 8 or 10 inches wide, and 12 inches tall. They contain water to a depth of 3 to 10 inches (see "Tidal conditions" below). The cross-sectional area of the tanks is kept small, as this, combined with the capacity of the pump, largely determines the rate of flow of water (but see note on swirling in the next section).

Tank connecting units

The pipes connecting one tank to the next, and those connecting the 'first' and 'last' tanks to the pump are made of black Alkathene. They are modified from units made commercially for plumbing purposes. The details are shown in figure 5. These units were designed so that a single tank may be removed easily from the series for repair or maintenance. A siphon made of the same material is kept in reserve and is used to maintain the circulation should it be necessary to remove a tank. The first and last tanks are provided with a 'bend' (fig. 4) to which are bolted the adapters for receiving the water from, and conducting the water to, the pump. In all cases watertight seals are obtained by adding a film of vaseline (while the units are dry).

The connecting units are fitted as near to the bottoms of the tanks as possible.

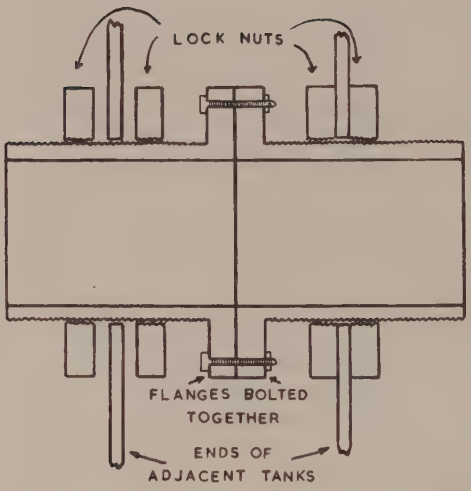

FIGURE 5.—Tank-connecting units.

Swirling of the water is to be encouraged, but increasing the speed of entry of water with a smaller bore pipe (to get more swirling) results in an increase in the head of water and reduces the efficiency of the pump, so that a compromise is necessary; 2-inch bore pipes are used on the aquarium here.

Tidal conditions

A closed circulation system enables tidal conditions to be easily simulated by a sluice gate. A round hole is cut in one of the broad sides of a Perspex box so that it may be fixed to a tank connecting unit. The opposite broad side is cut down so as to be at the level of the water. The sluice gate, also of Perspex, slides in slots against this side of the box. One end of a pivoted arm is attached to the sluice gate, the other end resting on a cam turned by an electric clock motor. Thus the sluice gate rises and falls once every 12 hours; as it rises, the depth of water on the upstream side increases, and therefore decreases on the downstream side; as the gate falls, the two water levels reverse this change until they become equal again.

Tidal conditions are necessary for some intertidal organisms. It has been found that limpets, for example, live indefinitely in these tidal conditions, but were difficult to keep for long without them.

Filtration

For the reasons already stated the water in the aquarium is not filtered. It would be expected that detritus would slowly collect in the tanks, and this does happen. This detritus appears to have no deleterious effects on most organisms, but it does tend to swamp some smaller, sedentary types.

An obvious method of control is to remove it from time to time, but in the absence of knowledge as to the nature of the detritus this practice might upset the chemical balance of the aquarium. A better method is to introduce detritus feeders; hermit crabs have been used successfully.

It is worth mentioning that in spite of the slow accumulation of detritus the water always remains perfectly clear.

Lighting

Fluorescent lighting is provided for some tanks. The amount of lighting, including the time it is switched on, is adjusted so that the photosynthetic organisms (especially diatoms) keep the pH of the water to about 8.1–8.2.

ACKNOWLEDGMENTS

It is a pleasure to record my appreciation of the hospitality of the Director and Staff of the Stazione Zoologica, Naples, where these ideas about marine aquariums were first conceived, and the helpful discussions with many colleagues. I should also like to thank Mr. A. Yeoman, Mr. A. Gall, and Mr. R. A. Fox whose craftmanship made the aquarium possible.

LITERATURE CITED

BEVELANDER, GERRIT.

1952. Calcification in molluscs. III. Intake and deposition of Ca^{45} and P^{32} in relation to shell formation. Biological Bulletin, vol. 102, No. 1, pp. 9–15.

COOPER, L.H.N.

1948a. Particulate ammonia in sea water. Journal of the Marine Biological Association of the United Kingdom, vol. 27, No. 2, pp. 322–325.

1948b. The distribution of iron in the waters of the Western English Channel. Journal of the Marine Biological Association of the United Kingdom, vol. 27, No. 2, pp. 279–313.

1948c. Some chemical considerations on the distribution of iron in the sea. Journal of the Marine Biological Association of the United Kingdom, vol. 27, No. 2, pp. 314–321.

GOLDBERG, E. D.

1952. Iron assimilation by marine diatoms. Biological Bulletin, vol. 102, pp. 243–248.

HALE, E. J.

1957. The problem of keeping marine animals. Royal Physiological Society of Edinburgh, Proceedings, vol. 26, pp. 19–24.

1960a. Marine aquaria in the laboratory. Advanced Science, vol. 16, pp. 106–109.

1960b. Contractility and hydroplasmic movements in the hydroid *Clytia johnstoni*. Quarterly Journal of the Microbiological Sciences, vol. 101, pp. 339–350.

HARVEY, HILDEBRANDE WOLFE.

1937a. The supply of iron to diatoms. Journal of the Marine Biological Association of the United Kingdom, vol. 22, pp. 205–219.

1937b. Note of colloidal ferric hydroxide in sea water. Journal of the Marine Biological Association of the United Kingdom, vol. 22, pp. 221–225.

1957. The chemistry and fertility of sea waters. 2d ed. Cambridge University Press. 234 pp.

OLIVER, JAMES H.

1957. The chemical composition of the sea water in the aquarium. Proceedings of the Zoological Society of London, vol. 129, No. 1, pp. 137–145.

ROBERTSON, JAMES D.

1941. The function and metabolism of calcium in the Invertebrata. Biological Reviews of the Cambridge Philosophical Society, vol. 16, No. 2, pp. 106–133.

SPENCER, C. P.

1956. The bacterial oxidation of ammonia in the sea. Journal of the Marine Biological Association of the United Kingdom, vol. 35, No. 3, pp. 621–630.

WILBUR, KARL M., and LOUISE H. JODREY.

1952. Studies on shell formation: I. Measurement of the rate of shell formation using Ca^{45}. Biological Bulletin, vol. 103, No. 2, pp. 269–276.

ZOBELL, CLAUDE E., and D. QUENTIN ANDERSON.

1936. Observations on the multiplication of bacteria in different volumes of stored sea water and the influence of oxygen tension and solid surfaces. Biological Bulletin, vol. 71, No. 2, pp. 324–342.

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A SUBSIDIARY HOT-WATER CIRCUIT IN AN AQUARIUM FED BY AN OPEN CIRCUIT

By L. Barriety

Musée de la Mer, Biarritz, France

Abstract.—An effective method is described for recirculating and filtering heated sea water, in order to alleviate the thermal loss entailed when warmed water is wasted.

One of the disadvantages of supplying an aquarium with sea water using an open circuit is the lack of flexibility from the thermal point of view. The temperature at which the water is received in such an installation is closely related to the temperature of the sea water at the point where it is pumped, and if for any reason—for instance, maintenance of tropical fish or of organisms from polar regions—it is necessary to heat or cool the water, this conditioned water will be drained off almost entirely, without any practical possibility of recovery.

But in these temperate regions it frequently occurs that subtropical animals may be caught from the sea, and if one desires to keep them alive for several years it becomes necessary to supply them with heat during the winter. If they are small, and if the tank where they live is rather small, one may be content to heat the water by any means (the most frequently used means is an immersion heater) and to let the warmed water go down the drain, since the weak output does not involve a very considerable expenditure of heat. Things are entirely different in the case of large animals requiring tanks that are sometimes tens of cubic meters in size. In such a case, the recovery of the water after it has passed through the tanks affords a substantial saving of heat and is therefore necessary. This procedure is used in the turtle (*Caretta caretta*) tank of the Musée de la Mer at Biarritz, which has a volume of 18 cubic meters.

To maintain sufficient limpidity in the tank, it is necessary to ensure a more or less total renewal of the water every 24 hours, and the daily consumption is close to 15 cubic meters. On the other hand, to provide good living conditions for the turtles, the water temperature must be maintained at 17° to 18° C. In midwinter the water comes from the reserve tanks at 10° to 11° C. and is heated in a heat exchanger to 18° C. before it is introduced into the exhibit tank, which it leaves at a temperature of 17° C. It is this water that is drained off, with a consequent loss of the magnitude of 75 therms; this represents, for just one tank, a very considerable waste.

Accordingly, we have considered it appropriate to alleviate that loss as much as possible by recovering the water and reusing it after filtration. Consequently, for this turtle tank, a separate circuit was installed at the outlet of the exhibit tank *A* (fig. 1) which includes a filter with two compartments, a heat exchanger, and a rotary pump which accelerates the circulation. The most interesting element of this

This paper was prepared in French; it was translated into English by a commercial translating service.

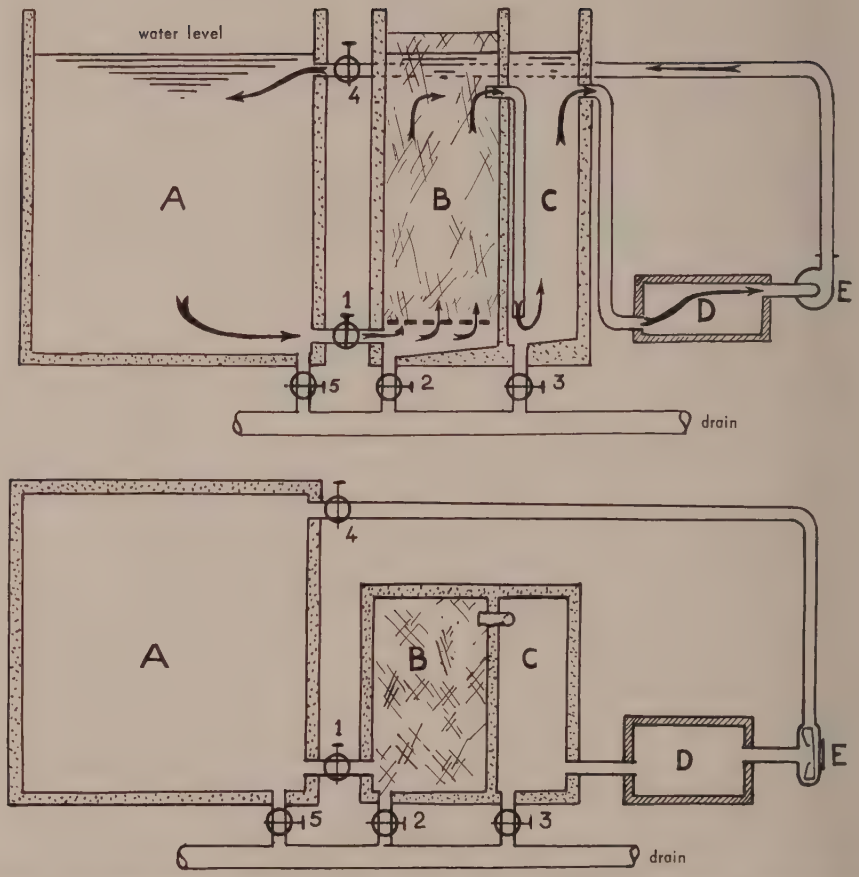

FIGURE 1.—Filtering system—side view above, top view below: *A*, concrete tank; *B*, filter chamber; *C*, storage compartment; *D*, heat exchanger; *E*, centrifugal pump. *1*, *2*, *3*, *4*, and *5* are gate valves.

device is the filter. It consists essentially of a rectangular basin of reinforced concrete from which the flow may be interrupted by means of a gate valve (1). The dirty water arrives from the tank in the lower compartment of the filter (*B'*); the abrupt loss of speed of the water, which flows from the pipe into a much larger vessel, causes a rapid deposition of the largest impurities. The bottom is at a 10-percent incline, with a gate valve (*2*) at its lowest point; this permits easy evacuation of the slush formed. From this lower compartment the water passes through a perforated slab and reaches the filter proper (*b*) which consists first of a layer of oyster shells designed to fix the nitrites, and then of beds of gravel of gradually decreasing size ranging from 5–7 cm. to 1–1.5 cm. The water in the upper part of this filter is sufficiently transparent to be reused in the exhibition tank.

The water is caught once more by a tube which conveys it into a last storage compartment (*C*) where it may still lose, by gravity, a few elements that might have

been able to pass through the filtering beds. The lower part of this component of the filter may be cleaned by opening a gate valve (*3*), releasing for drainage a few liters of water from the bottom. Finally, the water will be caught by a pipe system above the last compartment of the filter, and will traverse a heat exchanger (*D*) of 18 kw. where it will be reheated to 18° C., the temperature desired, and finally a centrifugal pump (*E*) which has an output of 2 m.³/h. and is driven by a small 1-kw. electric motor. Even though the pump has a small output, it has enough power for the requirement (about 15 m.³/day); moreover, it does not operate continuously, because the closing and opening of the electric circuit are controlled by an hourly break switch.

The filtering gravel beds are very easy to clean. The gate valve (*2*) is opened, and the pressure is sufficient to direct a jet of water to the upper part of the tank. Some 10 minutes suffice for cleaning the gravel almost completely. It is left to drip off for a few minutes, then the system may be put into operation.

It is unnecessary to add that the installation operates only during the winter. The open-circuit feeding will be reestablished as soon as the pump water reaches a temperature of 16° to 17° C.

It should be understood that the method explained here is only a makeshift device; still, its results are acceptable, and it provides a considerable saving of thermal energy.

EXPERIMENTAL SEA-WATER SYSTEMS FOR REARING FISH LARVAE

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Abstract.—Marine fish are not easy to rear in aquariums, but encouraging results have been achieved for the plaice (*Pleuronectes platessa*) in closed circulation at Lowestoft. Two temperature-controlled sea-water systems are described, both using illuminated green algae for metabolite regulation, and one having a measure of bacterial control by ultraviolet light. Survival is better in open circulation where metabolite accumulations are less severe. Two further hatchery systems are outlined; one delivering a continuous flow of filtered and temperature-adjusted sea water for local experimental use, and the other for conducting long-term experiments on chemical factors affecting egg and larval survival.

U.S. Fisheries Commissioner Spencer F. Baird (1880) pioneered the first attempt to rehabilitate a depleted sea fishery by large-scale artificial propagation in marine hatcheries. His efforts were influenced by the discovery of G. O. Sars (1866) that a cod egg could be artificially fertilized in much the same way as a freshwater fish egg. The American example stimulated European interest; hatcheries were soon erected in Norway and Britain, but after several decades of operational use, with no solid returns, hatchery practice fell into disrepute. Technical development became stunted by the inability of pioneers to rear sea fish in large numbers beyond their tender early stages. Production was measured in terms of eggs and early larvae liberated into the sea, rather than tough fish with reasonable chances of further survival.

Even in those early days, certain species had been reared through the postlarval phase, including the herring (Meyer, 1880), the cod (Rognerud, 1887), the plaice (Dannevig, 1897), the sole (Fabre-Domergue and Bietrix, 1905) and the turbot (Anthony, 1910), but all on an experimental scale. Mass production in quantities sufficient to influence the yield of a fishery still remains a fish culturist's dream. Work towards this end began at Lowestoft in 1957, the main aim being to develop a small-scale technique which could guarantee a consistent annual target production of metamorphosed plaice (*Pleuronectes platessa*) from sea-spawned eggs. By 1960, up to 10-percent survival had been achieved in closed circulation; this was increased to 33 percent during 1961 in open circulation at Port Erin, Isle of Man, giving survivor densities of 166 fish per square foot of tank bottom.

So far, our technique has developed in an empirical fashion—making mistakes and learning to avoid them. Now that a satisfactory procedure has been worked out, it will be possible to start a more systematic study of factors affecting larval survival, with a reasonable expectation of positive results. This information will help us to streamline our technique and to approach the problem of mass production with economy of effort. Complete

technical details and results will begin to appear in the Journal du Conseil Permanent International pour l'Exploration de la Mer during 1962. This paper deals only with the design and operation of our closed and open sea-water circulations.

CLOSED CIRCULATIONS AT LOWESTOFT

The 50-gallon system

In the absence of running sea water at Lowestoft, we were obliged to start fish-rearing studies in static conditions and closed circulations. It soon became evident that small static tanks were unsuitable for survival beyond the early larval stage. By 1957, a closed circulation with limited physicochemical control of water conditions had been designed. It incorporated a fundamental principle of tropical-aquarium technique—the use of photosynthesizing plants to control the CO_2 concentration and stabilize the pH, as well as to remove some end products of protein metabolism and to add oxygen.

The pH can be regulated by chemical means—the addition of lime, for instance (Cooper, 1932), or sodium bicarbonate (Breder and Smith, 1932)—but these methods involve changes in the balance of salts. The CO_2 may also be removed by vigorous aeration (Downing, 1958); cod larvae, however, are known to be harmed by oxygen supersaturation (Henly, 1952). Nitrogenous end products of metabolism cannot be controlled by purely chemical or physical means without affecting the survival of fish in circuit.

The design of our first circulation is shown in figure 1. It has three main components: (*a*) a 30-gallon covered reservoir, (*b*) a covered, temperature-controlled water bath housing two moulded-glass tanks (incubators) each of 8 gallons' operational capacity, and (*c*) a polythene header tank containing illuminated fronds of *Enteromorpha intestinalis* attached to stones. A small centrifugal pump under the control of a mercury float switch intermittently transfers water from the reservoir to the header. The pump volute is best constructed from stainless steel or high-density polythene. The header tank can contain any sessile green alga able to withstand lengthy immersion in water of high salinity. Fronds and substrate must be thoroughly washed to remove mud and debris before use. Tungsten lighting can be used, but a fluorescent source is preferable because it produces less heat. With flexible switching arrangements and a little practice, we found it possible to adjust the light intensity manually, giving a stable pH of 8.1 for days at a time.

Sea water flows by gravity from the header into the incubators at a controlled rate after passing through a nylon mesh screen to hold back plant debris. In circulations of this size, a drip feed of 4 liters per hour per incubator is a practical rate of flow for pelagic eggs and larvae at temperatures up to 10° C. The optimum irrigation rate may differ from species to species; clumped demersal eggs are likely to benefit from a rapid flow. Slow rates of flow can be adjusted by controlling the number of drops falling per unit of time past a "window" (perspex tube) fitted into the inlet system, whilst periodic variations in dropping rate are minimized by setting the header float switch to operate within narrow changes of water level.

Incubator design is a very important factor. Plaice and most other pelagic marine fish larvae are delicate creatures, not adapted to live in constant contact with surfaces. Tanks must therefore be simply constructed, with smooth internal surfaces and no unnecessary inclusions. Two closely apposed surfaces can act as

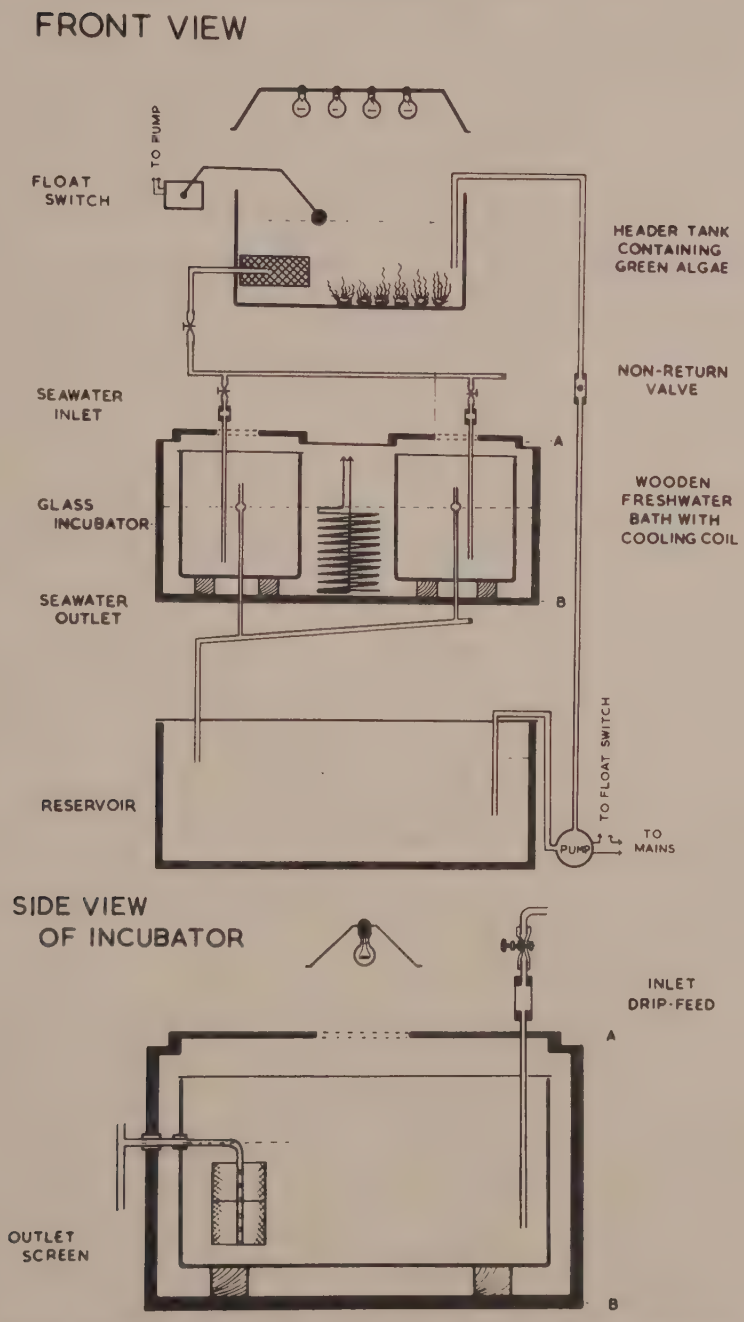

FIGURE 1.—Closed sea-water circulation for rearing plaice: 50-gallon capacity.

a lethal trap; crevices in tank walls are a particular menace—larvae swim into them and seem unable to back out. One incubator inclusion is necessary, however, and that is some sort of screen to prevent eggs, larvae, and larval food from being flushed away. The outlet system shown in figure 1 consists of a submerged vertical polythene pipe, corked at its lower end and perforated along part of its length. The perforations are covered by 155-meshes-per-inch nylon bag, held at a distance by three polythene disks surrounding the pipe. This screen is connected to a horizontal overflow tube passing through a watertight seal in the incubator wall. The nylon mesh is fine enough to retain *Artemia salina* nauplii, a convenient and reliable larval food organism. Plaice larvae are visual feeders; tanks require overhead illumination at water surface intensities around 500 lux during "first feeding." Later on, dimmer lighting helps to depress larval activity in overcrowded conditions. It is also important to black out the walls and bottoms of feeding tanks, since food organisms are more easily seen and captured by early feeders against a dark background.

To regulate water temperature in warm surroundings, incubators are immersed in a fresh-water bath cooled by a copper coil linked to a thermostatically controlled domestic refrigerator unit. The fresh water can be slowly circulated around the incubators by hard aeration. Vertical temperature gradients are inevitable in water-cooled tanks at high ambient temperatures and slow irrigation rates; the agitation required to break them down is detrimental to delicate fish larvae. Controlled air temperature systems are more efficient than water baths. A slow salinity increase occurs in any closed circulation, owing to evaporation. This can be offset by frequent routine additions of distilled water to the reservoir. Copper distillation is not recommended.

In retrospect, the following improvements could be made to the apparatus as described:

1. A substantial increase in reservoir volume.
2. Water-bath cooling replaced by air-temperature control.
3. Automatic pH adjustment, by linking a pH meter control unit to a variable light source above the header.
4. Automatic salinity adjustment, by coupling a salinometer and control to a solenoid valve regulating the input of distilled water into the reservoir.
5. A glass-wool filter inserted at the point where the common outlet pipe discharges into the reservoir.
6. Bacterial control in the reservoir by means of a low-power ultraviolet unit (see later), and in the incubators by occasional dosing with antibiotic mixtures.

Results were encouraging, even without the suggested improvements. They demonstrated that a closed circulation could be used to rear plaice from the egg stage through and beyond metamorphosis—a period of 3 to 4 months—at a minimum ratio of 1 survivor per 2.5 liters of sea water.

The 3,500-gallon system

Our expanded closed circulation (fig. 2), built in 1959, has two main components; a sunken concrete reservoir (15 by 10 by 4 feet) and an adjacent brick hatchery (22 by 13 by 8 feet). The reservoir contains roughly 2,500 gallons of offshore seawater. *Enteromorpha* is once again used to control metabolites, being submerged at a depth of 6 inches, on large trays consisting of polythene film sewn to a wooden framework with no metal fastenings. The alga receives illumination at night from fluorescent tubes arranged in banks of four above the trays. Each bank hangs by a nylon rope and pulley (permitting vertical adjustment) from a stout timber gallows spanning the tank.

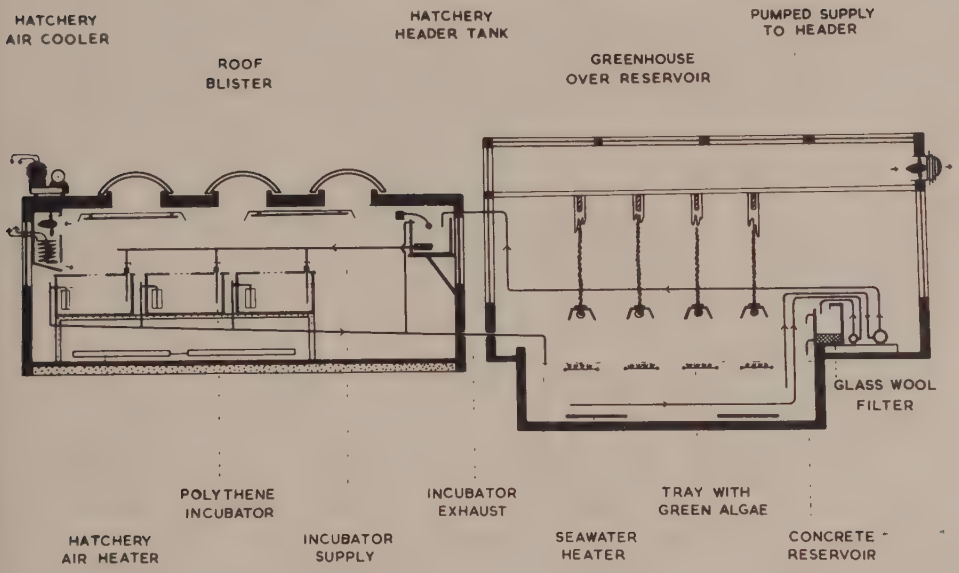

FIGURE 2.—Closed sea-water circulation for rearing plaice: 3,500-gallon capacity.

A greenhouse covers the reservoir, so it receives natural lighting during the day.

Low-wattage immersion heating panels, embedded in epoxy resin and controlled by floating thermostats, counteract excessive cooling of reservoir water during cold weather. For 2 years there were no safeguards against rapidly rising water temperatures in spring and early summer. A separate cooling circulation combined with filtration and bacterial control was installed in 1961 (fig. 3). Sea water is pumped at a fast rate from the far end of the reservoir into three plywood boxes irradiated with ultraviolet light. After treatment, water overflows out of the boxes, through glass-wool filters, into three 100-gallon asbestos-cement tanks, each containing two refrigeration coils made up from 50-foot lengths of ¾-inch steel tubing. All six coils are connected to a 3-horsepower motor and compressor controlled by a thermostat in the reservoir. Water overflows from the cooling units back into the main tank.

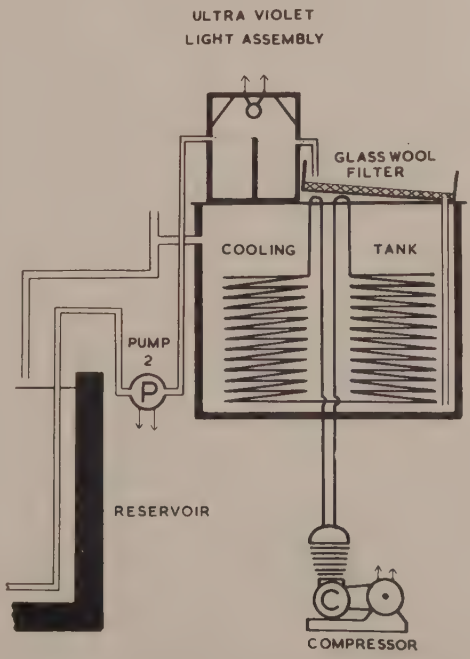

FIGURE 3.—Reservoir cooling circulation combined with filtration and ultraviolet irradiation.

A small electric pump operated by a mercury float switch transfers sea water from the reservoir to a header tank in the hatchery. From there it is gravity-fed to nine 5- by 2- by 2-foot black polythene rearing tanks on metal stands. Although much bigger than the glass incubators shown in figure 1, their design is essentially the same. Water returns to the reservoir along a common exhaust tube. The inside of the hatchery is painted white; glass "blisters" in the hatchery roof provide overhead illumination during the day, augmented by four 80-watt fluorescent tubes. Hatchery air temperature is stabilized by heaters in cold weather and two small air coolers in summer.

Metal surfaces in contact with sea water must be kept to a minimum; among the cheaper metals only stainless steel is safe. Metallic fittings are best coated with epoxy resin to prevent corrosion and the release of harmful ions; mild-steel coils treated in this manner can be used for cooling sea water by direct immersion. Filters are necessary to check undesirable phytoplankton blooms in the reservoir and to reduce the surfaces available for bacterial attachment. There is some doubt about the efficiency of our bactericidal arrangements in 1961; the matter is discussed in the next section.

In retrospect, it was a mistake to separate hatchery and reservoir. Both components should be housed in the same insulated building equipped with air-temperature control. Sunken concrete reservoirs can be replaced by fiberglass tanks above floor level; direct water-temperature control systems then become superfluous. Natural lighting may be an advantage for efficient algal photosynthesis, and could be provided by double-glazed panels in the roof. Fluorescent lighting at night is in this case preferable to tungsten, on grounds of heat production, which can be further minimized by siting lamp-control gear outside the building.

Bacterial control in closed circulation

Oppenheimer (1955) demonstrated the possible value of bacterial control by antibiotics in marine fish hatcheries. Walne (1958) also used antibiotics to increase the survival rates of oyster larvae in experimental tanks. Bacterial populations are usually higher inshore than offshore (ZoBell, 1946). The plaice and many other sea fishes spawn in virtually oceanic waters with a low bacterial count. In the rich organic environment of a closed circulation the bacteriological problem must be greatly magnified. Even at low incubation temperatures less than 6° C., plaice egg shells become covered with epiphytic bacteria, a condition seldom occurring in the sea. The effect of shell contaminants on final survival to metamorphosis has not yet been systematically assessed; a start is to be made during the spring of 1962.

Wood (1961) has studied the use of ultraviolet light for bacterial control in seawater circulations, and our system is based on his design. Reservoir sea water flows at a total rate of 300 gallons an hour through three plywood boxes lined with epoxy resin (fig. 4). Each lid contains two 15-watt low-pressure ultraviolet tubes backed by an aluminium reflector. Water enters the box at a low level and passes over a longitudinal plywood weir before overflowing into the filters. We were unable to test the bactericidal efficiency of the system before installation; an opportunity to do so occurred later on, when the plaice-rearing experiments were finished.

A supply of 450 gallons of turbid estuary water in a concrete tank was continuously pumped through two of our ultraviolet boxes at a fast rate of 520 gallons per hour. Water samples were withdrawn at frequent intervals, and bacterial

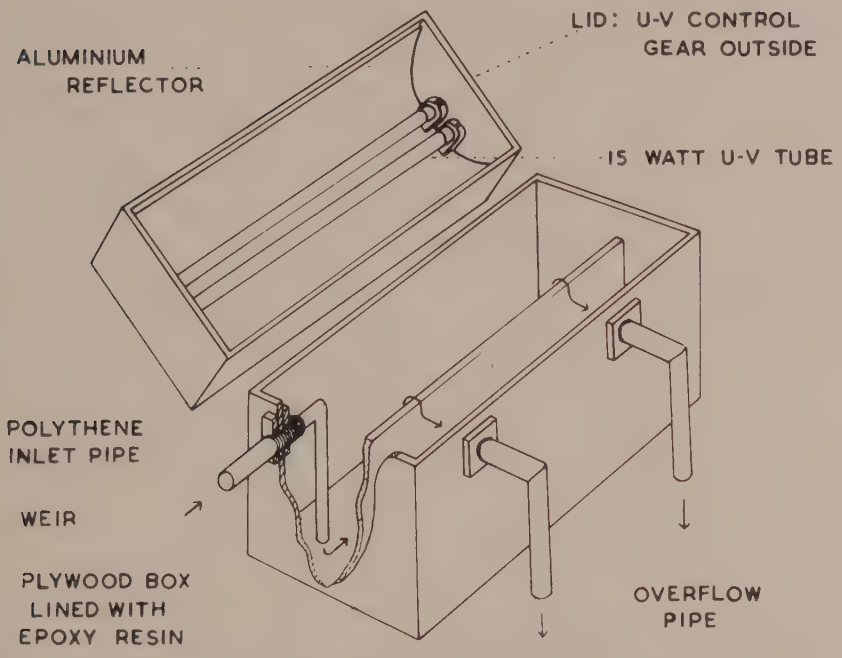

FIGURE 4.—Design of ultraviolet bactericidal unit.

populations were assessed by mixing 1-ml. volumes with ZoBell's 2216 medium using the standard pour-plate method. Duplicate bacterial counts were also derived from the dropping technique of Miles and Misra (1938). Even at a flow of 260 gallons per hour per box, water leaving the outlets was virtually sterile after treatment. Within 6 hours, the originally high bacterial counts characteristic of inshore water had dropped to a level similar to that in the open sea (fig. 5). The treatment was continued overnight, and sampling resumed the following morning. By this time the water in the reservoir was perfectly clear and the filters were caked with estuarine debris. The filter bypass was then closed and the whole flow was directed through the ultraviolet boxes alone. Figure 5 demonstrates (*a*) the bacterial efficiency of these units at a high rate of flow and (*b*) the recontaminating influence of dirty filters in a bypass circuit.

The hourly flow in our 1961 plaice-rearing circuit was only one-tenth of the reservoir volume. Thus the bactericidal potential of the system was not fully exploited. In addition, the filters were incorrectly sited—they should be placed before and not behind the source of ultraviolet radiation. Given rapid water turnover, reservoir bacteria can undoubtedly be controlled by direct irradiation. However, the method is not easily applied to bacterial control in actual rearing tanks, where periodic dosing with antibiotics may be necessary, at least during the egg phase.

FIGURE 5.—Survival curve of marine bacteria irradiated in closed circulation. Solid line indicates pour plate (1-ml. water samples in ZoBell's 2216 medium). Dashed line indicates Miles and Misra method (1/50-ml. drops on ZoBell's medium). Plates incubated at 25° C. for 24 hours. Mean water temperature 18° C.

OPEN CIRCULATION AT PORT ERIN, ISLE OF MAN

Metabolites are continually removed in open circulation, and survivals of plaice larvae are correspondingly higher. A mean survival of 33 percent was achieved in the control tanks of a salinity experiment at Port Erin during 1961. This is several times greater than the expected result in closed circulation at Lowestoft, using the same basic tank design and handling technique.

Hatchery sea water is usually of the inshore variety; certain controls are still necessary. For instance bacterial control is needed either in the main reservoirs or locally at the point of flow into experimental tanks. Filtration is also important in open circulation since suspended particles provide a "foothold" for sessile bacteria. The problem of temperature control still persists with diurnal fluctuations in the coastal environment; salinity similarly varies according to rainfall and local runoff.

Local filtration and temperature control

A simple apparatus to continuously filter incoming hatchery sea water, and to lower its temperature before delivery into experimental tanks, is shown in figure 6. It consists of a 10-gallon polythene carboy fitted with a high-level overflow pipe and a low-level delivery tube leading into an insulated 40-gallon asbestos-cement header tank. The tank contains a resin-coated steel cooling coil coupled to a ⅓-horsepower refrigerator unit outside the hatchery, controlled by a sensitive thermo-

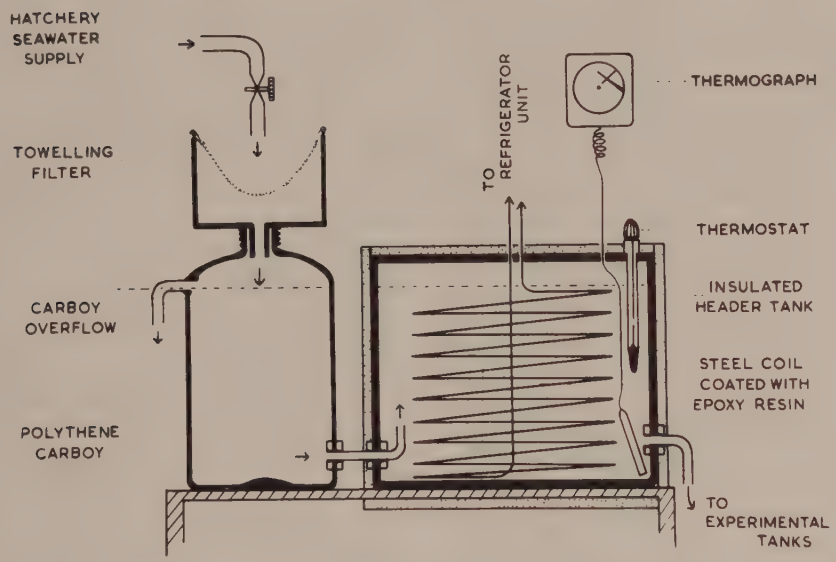

FIGURE 6.—Open-circulation apparatus providing local filtration and temperature control.

stat in the header. Hatchery sea water passes into the carboy through two layers of fine-weave toweling, at a rate slightly in excess of experimental requirements. The filtered overflow runs to waste. Temperature-adjusted water leaving the header is continually replaced by filtered water from the carboy. Some mechanical stirring may be necessary in the control tank; no float switches or ball cocks are required. If the temperature of the incoming seawater is lower than required, an aquarium heater replaces the cooling coil. Both heater and cooling coil can be used to counter one another when the temperature of the incoming supply is very variable. In practice, the unit delivered 30 gallons per hour of filtered sea water at 7° C., with the main hatchery supply standing at 10° C.

The horizontal stippled strip below the supporting platform of the header tank is a sheet of expanded polystyrene insulation board, stuck on the underside. It represents a not-too-necessary refinement if the platform is of thick timber, and could be eliminated if one so chooses. The vertical and topside stippling similarly represents the insulating sheath of the tank.

Port Erin sea water is relatively clear, but in turbid conditions a finer filter system will be needed, with an increased filtration surface. A small-wattage bactericidal unit can easily be interposed between the filter and the constant-level carboy. The pipeline to rearing tanks, and the tanks themselves, must be insulated if hatchery air temperature is uncontrolled. An apparatus of this sort ran for 3 months during 1961 with no attention other than a daily change of filter.

A variable salinity apparatus in open circulation

Most salinity experiments on marine fish eggs and larvae have been confined to testing the effect of extremes on short-term survival in static conditions. We are more interested in the long-term effect

of slight differences in salinity. An open circulation is essential, since accumulating metabolites may mask a salinity effect. Figures 7 and 8 illustrate an experimental unit successfully used in 1961.

A measured amount of hatchery sea water is filtered through toweling into a leached asbestos-cement reservoir (100-gallon capacity) each morning, and a calculated volume of distilled water is added to give a desired lower salinity. After thorough mixing, this water is continuously transferred by a small airlift pump into a polythene header tank above the reservoir, at a rate slightly in excess of incubator requirements. A delivery manifold emerging from the front lower face of the header, conducts water at an equal and steady rate of 4 liters per hour into each of three 2- by 1- by 1-foot glass incubators. The header overflow is channelled back into the reservoir. This arrangement provides a constant head to facilitate delivery control.

The three glass incubators have the same design as that illustrated in figure 1. Their sides are shrouded in close-fitting jackets of black polythene film. The inlets deliver their flow below the water surface; each perforated outlet pipe has a vertical extension, also below the surface, screened with a fine nylon mesh bag held at a distance from the pipe by three polythene disks. The incubators sit side by side in a black fiberglass tank through which sea water slowly circulates from the main hatchery supply. This water bath is calculated to limit the effect, if any, of diurnal variations in hatchery air temperature. The outlet (strictly overflow) pipes of the inner glass tanks are extended through the side of the fiberglass water bath, to discharge into a common drain gutter. The bath has a plywood cover, treated underneath with epoxy resin, and painted on

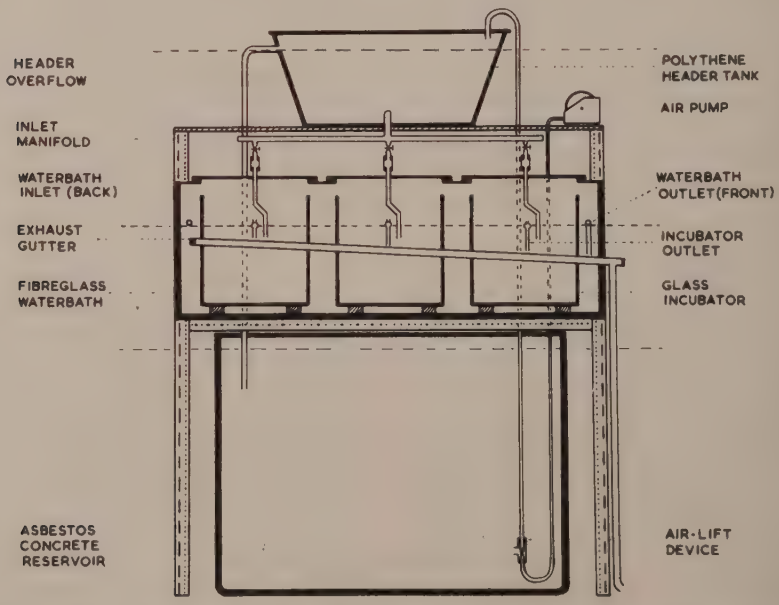

FIGURE 7.—Open-circulation apparatus designed to test long-term effect of salinity variation on the survival of plaice larvae: front view.

top. Hinged plywood flaps over large rectangular holes in the cover give access to the inner tanks. These flaps are provided with central slits covered by translucent polythene film, for admitting light. A prefabricated steel framework carries all components other than the reservoir, which stands on the floor, partly hidden under the water bath.

The volume of salinity-adjusted sea water made up each day is always more than that required for 24 hours' irrigation. Residual water is measured the following morning with a dipstick, and the amount of distilled water in the mixture calculated. Measured volumes of hatchery sea water and distilled water are then added to provide the next 24 hours' supply.

By this method it is possible to maintain a continuous flow of sea water adjusted to a salinity below that of hatchery supply, for long periods of time. Adjustments the other way can be made by adding suitable mixtures of salts. The experimental tanks are buffered against air temperature variation only. Stricter temperature standards would require a hatchery air-conditioning plant; alternatively, the water bath could be made part of an auxiliary closed fresh-water circulation with immersion heating or cooling. These triple tank units are virtually self-contained and can be used in replicate to test any long-term chemical effect on larval survival, without running the risks inherent in a static system.

All the closed and open circulations described in this paper have been successfully used to rear plaice larvae. Technical details such as optimum temperatures, light, salinity, pH, flow rate, and diet will vary from species to species, but these basic designs are recommended as a starting point in the experimental study of hatchery requirements for all marine fish with pelagic eggs.

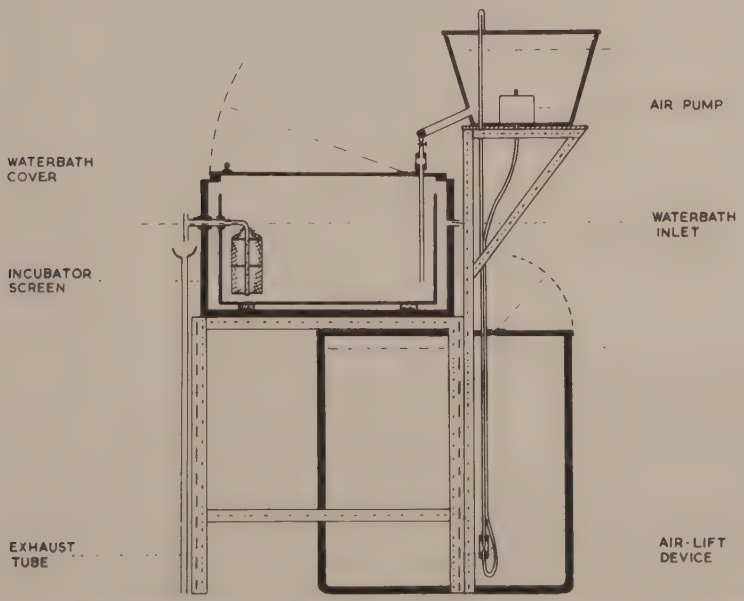

FIGURE 8.—Open-circulation apparatus designed to test long-term effect of salinity variation on the survival of plaice larvae: side view.

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SUMMARY

Hatcheries were built in America and Europe at the turn of the nineteenth century to rehabilitate depleted sea fisheries by artificial propagation. They fell into disuse mainly as a result of ill-developed techniques. Marine fish are difficult to rear beyond the tender larval stages, even on a small scale, but a plaice-rearing technique has been empirically evolved at Lowestoft giving up to 10-percent survival from egg to metamorphosis in closed circulation. Two temperature-controlled sea-water systems are described, both using illuminated green algae for metabolite regulation, and one having some degree of bacterial control by ultraviolet light.

Survival is better in open circulation, where the metabolite problem is minimized. A system for providing a continuous flow of filtered and temperature-adjusted sea water is described, together with an apparatus for conducting long-term experiments on chemical factors affecting larval survival.

LITERATURE CITED

ANTHONY, RAOUL L. F.
1910. The cultivation of the turbot. (Translated from the French. Proceedings of the Fourth International Fishery Congress, Washington, 1908) U.S. Bureau of Fisheries, Bulletin, vol. 28, part 2, pp. 859–870.

BAIRD, SPENCER F.
1880. Report of the Commissioner for 1878. U.S. Commission of Fish and Fisheries, pp. xv–lxiv.

BREDER, CHARLES M., and HOMER W. SMITH.
1932. On the use of sodium bicarbonate and calcium in the rectification of seawater in aquaria. Journal of the Marine Biological Association of the United Kingdom, vol. 18, No. 1, pp. 199–200.

COOPER, L. H. N.
1932. On the effect of long continued additions of lime to aquarium seawater. Journal of the Marine Biological Association of the United Kingdom, n.s. vol. 18, No. 1, pp. 201–202.

DANNEVIG, HARALD.
1897. On the rearing of the larval and post-larval stages of the plaice and other flatfishes. Scotland, Fishery Board, Scientific Investigations, Report for 1896, part 3, pp. 175–193.

DOWNING, A. L.
1958. Aeration in aquaria. Aquarist and Pondkeeper, vol. 23, No. 3, pp. 47–52.

FABRE-DOMERGUE, P., and E. BIETRIX.
1905. Développement de la Sole (*Solea vulgaris*). Travail du Laboratoire de Zoologie Maritime de Concarneau. Vuibert et Nony, Paris. 243 pp.

HENLY, EVA.
1952. The influence of the gas content of sea water on fish and fish larvae. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbaux des Réunions, vol. 131, pp. 24–27.

MEYER, H. A.
1880. Biological observations made during the artificial rearing of herrings in the western Baltic. Report of the U.S. Commission of Fish and Fisheries for 1878, pp. 629–638. (Translation)

MILES, A. A., and S. S. MISRA
1938. The estimation of the bactericidal power of blood. Journal of Hygiene, Cambridge, vol. 38, pp. 732–749.

OPPENHEIMER, CARL H.
1955. The effect of marine bacteria on the development and hatching of pelagic fish eggs, and the control of such bacteria by antibiotics. Copeia, 1955, No. 1, pp. 43–49.

ROGNERUD, CARL
1887. Hatching cod in Norway. Bulletion of the U.S. Fish Commission, vol. 7, pp. 113–119. (Translation)

SARS, GEORGE O.
1866. Om Vintertorskens, (*Gadus morrhua*). Forplantning og Udvikling. Forhandl. Vid. Selsk. Christiana, 1866. Translation in Report of the U.S. Commission of Fish and Fisheries for 1873–74 and 1874–75, Appendix A, pp. 213–222.

WALNE, P. R.
1958. The importance of bacteria in laboratory experiments on rearing the larvae of *Ostrea edulis* (L.). Journal of the Marine Biologi-

cal Association of the United Kingdom, vol. 37, No. 2, pp. 415–425.

Wood, P. C.

1961. The principles of water sterilisation by ultra-violet light, and their application in the purification of oysters. Ministry of Agriculture, Fisheries and Food, London, Fishery Investigations, ser. 2, vol. 23, No. 6. 48 pp.

ZoBell, Claude E.

1946. Marine microbiology. Chronica Botanica Co., Waltham, Mass. 240 pp.

A WORKING BIBLIOGRAPHY ON REARING LARVAL MARINE FISHES IN THE LABORATORY

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Abstract.—The literature available on bibliographic resources on rearing larval marine fishes in laboratory aquariums is reviewed critically; the list of references papers of special interest are designated. A list of marine telcost fishes reared in captivity is included.

It has been said that God made an animal to solve every problem in physiology and that the principal task of the experimenter is to find the species most suited to his needs. Although this statement contains a greater element of faith than even those who would never use it impiously might realize, the number of different laboratory animals available to the experimental biologist has continued to increase over the years along with the increase in number and variety of experiments.

As experimental animals, however, fishes have lagged behind the members of the other vertebrate classes, and only a minuscule fraction of the estimated 15 to 40 thousand species has found its way into the laboratory. The relatively remote phylogenetic position of the fishes and a few of their specific attributes, such as smallness of cells, have made them unpopular, but the principal obstacle to a more widespread use of fishes as laboratory animals is their limited ability to maintain homeostasis, which makes them delicate experimental subjects and establishes quite rigid requirements for their successful maintenance in captivity. This has been particularly true of the marine species, which are generally much more stenokous than those inhabiting fresh or brackish waters. Moreover, the limitations imposed by the inherent stenoky of marine fishes are aggravated by the difficulty of establishing a stable environment in salt-water aquariums.

The same factors have impeded the domestication of fishes; no marine species has yet been domesticated, principally because no salt-water fish can be bred generation after generation in captivity (Atz and Pickford, 1959). Domestication is not necessarily a prerequisite for even extensive use in the laboratory—witness those laboratory favorites, the true frogs (*Rana* spp.) and the mummichog (*Fundulus heteroclitus*)—but all domesticated animals are, of course, available to the experimentalist as, for example, are rainbow trout (*Salmo gairdnerii*), carp (*Cyprinus carpio*), guppy (*Poecilia reticulata*), and Siamese fighting fish (*Betta splendens*). There would be an immediately realized monetary advantage in spawning and rearing the milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) for pondfish culture, but the potential value of being able to study under controlled conditions all phases of the life histories of the marine fishes that will soon provide the bulk of man's animal protein food is inestimable.

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About 50 years ago, artificial fertilization and incubation of the eggs of marine food fishes were carried out on a large scale in order to replenish defining natural stocks (e.g. see papers presented at the Fourth International Fishery Congress, Washington, 1908, which were published in 1910 in vol. 28 of the Bulletin of the U.S. Bureau of Fisheries). A critical look at the biostatistics involved (e.g. by Breder, 1922) demonstrated the uselessness of the procedure, which was eventually abandoned. Little systematic effort was made to rear the fish, since they were released or planted shortly after hatching, and Morris (1956) found that few data helpful for laboratory culture had been recorded.

Hertling (1932) and Morris (1956) give accounts of some of the early attempts to rear marine fishes from the egg. Much of the difficulty encountered was referred to the so-called critical period, when the larva, having used up its yolk supply, becomes dependent on other, external sources of food. While recognizing the radical nature of this vital change in larval nutrition, Morris makes it clear that in some species this is not an especially critical period, in the sense that no greater mortality is suffered at the time of the change. Marr (1956) reviews the evidence for a critical period in nature and concludes that it is not well demonstrated. Well taken is the point made by Morris that until the sensitivity of any given species has been determined, "the situation can be considered critical from the time of fertilization until organogenesis is completed."

Because of the rigid requirements of the eggs and larvae of marine fishes, data delimiting their tolerance of environmental factors and establishing optima should be especially useful. The series of papers by Bishai (1960a, 1960b, 1960c, 1961a, 1961b), supplemented by Holliday and Blaxter (1960) and Blaxter (1960), provides a convenient and comprehensive summary of this autecological approach. A point to be remembered, however, is that the limits of tolerance of eggs and larvae for conditions in captivity are often less than those exhibited in the wild, probably because of the generally suboptimal artificial environment. Moreover, not all of the environmental factors affecting fish larvae in nature have been studied. For example, attention has recently been directed to possible lethal effects of light (Perlmutter, 1961), and this element should be given consideration by the experimentalist.

The extreme sensitivity of fish larvae in general, and of those of marine species in particular, to substances in the water surrounding them is well recognized. Containers made of chemically inert materials such as glass and certain plastics must be used, preferably those that have never been in contact with formaldehyde, cleaning solution, and the like (Morris, 1956; Costello et al., 1957). It is now feasible to construct a small yet efficient circulatory system entirely of nonmetallic materials—a vital piece of laboratory equipment that remained an impractical ideal for many years. A satisfactory formula for artificial sea water in which fish larvae have thrived has yet to be developed, while MacGinitie (1947) has pointed out that natural sea water "rots on standing, and the resulting chemical and pH changes are lethal, particularly to larval forms." These changes are undoubtedly the result of the tremendous multiplication of bacteria in stored sea water; they may be controlled with antibiotics (Oppenheimer, 1955; Marshall and Orr, 1958; Rustad, 1960; Shelbourne, 1963a) or ultraviolet radiation (Wood, 1961; Herald et al., 1962), but cleanliness, aeration, filtration, and storage in the dark remain the principal means of maintaining sea water in a

satisfactory condition. Since eggs and larvae are sensitive to metabolic wastes—ammonia and perhaps other substances—crowding is to be avoided.

One of the knottiest problems in raising marine fishes concerns their nutrition. Morris (1955, 1956), Qasim (1959), and Hirano (1963) experimented with various foods and determined that one of the most successful was newly hatched brine shrimp (*Artemia salina*). A general account of this phyllopod crustacean and its use may be found in Dempster (1953). The San Francisco Aquarium Society and the California Academy of Sciences are sponsoring the publication of a comprehensive bibliography on *Artemia*, which should be published by the Society during 1964. The compendium edited by Needham et al. (1937) contains a section devoted to salt-water aquariums as well as instructions on rearing several kinds of marine invertebrates.

MARINE TELEOST FISHES REARED IN CAPTIVITY

A summary of marine teleost fishes which have been successfully reared in captivity from the egg is given in the following list:

Family Clupeidae:
- Atlantic herring, *Clupea harengus harengus* Linnaeus. [Kotthaus, 1939; Soleim, 1950; Dannevig and Dannevig, 1950; Dannevig and Hansen, 1952; Blaxter and Hempel, 1961a, 1961b; Bishai, 1961c; Blaxter, 1962.]

Family Gadidae:
- Atlantic cod, *Gadus morhua* Linnaeus. [Burd and Jones, 1948; Dannevig and Dannevig, 1950; Dannevig and Hansen, 1952; Dannevig, 1963; Wise, 1963.]

Family Gasterosteidae:
- Threespine stickleback, *Gasterosteus aculeatus* Linnaeus. [Leiner, 1934; Heuts, 1947.]

Family Aulorhynchidae:
- Tube-snout, *Aulorhynchus flavidus* Gill. [Morris, 1956.]

Family Syngnathidae:
- Spotted seahorse, *Hippocampus erectus* Perry. [Herald and Rakowicz, 1951; Simpson, 1957.]
- Dwarf seahorse, *Hippocampus zosterae* Jordan and Gilbert. [Strawn, 1954, 1958.]

Family Sparidae:
- Black porgy, *Milio macrocephalus* (Basilewsky). [Kasahara et al., 1960.]

Family Embiotocidae:
- Barred surfperch, *Amphistichus argenteus* Agassiz. [Triplett, 1960.]
- Shiner perch, *Cymatogaster aggregata* Gibbons. [Triplett, 1960.]

Family Scombridae:
- Black skipjack, *Euthynnus lineatus* Kishinouye. [Clemens, 1956.]

Family Cottidae:
- Bald sculpin, *Clinocottus recalvus* (Greeley). [Morris, 1956.]
- Fluffy sculpin, *Oligocottus snyderi* Greeley. [Morris, 1956.]

Family Blenniidae:
- Butterfly blenny, *Blennius ocellaris* Linnaeus. [Garstang, 1900.]
- Shanny, *Blennius pholis* Linnaeus. [Qasim, 1955, 1959.]

Family Pholidae:
- Rock gunnel, *Pholis gunnellus* (Linnaeus). [Qasim, 1955, 1959.]

Family Atherinidae:
- Atlantic silverside, *Menidia menidia* (Linnaeus). [Rubinoff, 1958.]
- Topsmelt, *Atherinops affinis* (Ayres). [McHugh and Walker, 1948.]
- Jacksmelt, *Atherinopsis californiensis* Girard. [Morris, 1956.]
- California grunion, *Leuresthes tenuis* (Ayres). [McHugh and Walker, 1948; Morris, 1956.]

Family Bothidae:
- Turbot, *Scophthalmus rhombus* (Linnaeus). [Anthony, 1910.]

Family Pleuronectidae:
- Plaice, *Pleuronectes platessa* Linnaeus. [Rollefsen, 1939; Dannevig and Dannevig, 1950; Dannevig and Hansen, 1952; Shelbourne, 1956, 1963a, 1963b; Rustad, 1960; Shelbourne, Riley and Thacker, 1963; Riley and Thacker, 1963.]
- Lemon sole, *Microstomus kitt* (Walbaum). [Dannevig and Dannevig, 1950.]

Family Soleidae:
- Sole, *Solea solea* (Linnaeus). [Dannevig and Dannevig, 1950.]

Family Tetraodontidae:
Puffer, *Fugu pardalis* (Timminck and Schlegel). [Shōjima, 1957.]
Family Batrachoididae:
Oyster toadfish, *Opsanus tau* (Linnaeus). [Straughan, 1957; Tracy, 1959; Dovel, 1960.]

From this list it can be seen that less than 30 species of marine teleosts have ever been reared in captivity from the egg. The few successes achieved can be attributed, in general, to two causes. The first concerns those economically important species on which it has been worthwhile to spend a good deal of time and effort (Atlantic herring, Atlantic cod, and the flatfishes), and the second those species with well-developed hatchlings or with special means of parental care, either of which might be considered to preadapt them to successful reproduction in the laboratory (sticklebacks, tube-snouts, seahorses, atherinids, surfperches, and toadfishes). We were surprised not to find any papers that describe the raising of *Fundulus heteroclitus* or some other marine cyprinodont in captivity, because members of the family Cyprinodontidae would seem to be eminently suitable for this kind of laboratory life. The eggs of the mummichog are easy to obtain and hatch (Gabriel, 1944; Costello et al., 1957), and the young have been raised to adulthood with simple equipment and relatively little effort (Alfred Perlmutter, New York University, personal communication). We have also seen sheepshead minnows (*Cyprinodon variegatus*) hatch from eggs laid in one of our exhibition aquariums and grow to near maturity with no special care whatsoever.

The work of Triplett (1960) indicates the possibility of culturing the young of the viviparous surfperches throughout the period of embryonic development, which would normally be spent within the ovary—just as that of Trinkaus and Drake (1952) had previously shown for the well-known poeciliid, the guppy. Perhaps similar techniques could be applied to the other types of livebearing marine fishes, i.e., the Clinidae (kelpfishes), Zoarcidae (eelpouts), and Brotulidae (brotulas). Those scorpionfishes and rockfishes of the family Scorpaenidae that bring forth living young are truly ovoviviparous, however, and their newborn young are no further developed than those of the scorpaenids that lay eggs; indeed, Morris (1956) was unable to carry newly born *Sebastodes goodei* to metamorphosis. A priori, it would seem that the best chance for success would be with a form lying somewhere between the extremes of true ovoviviparity and viviparity, since the latter would involve placentalike structures and almost complete dependence of offspring on mother for nutrition, for which it might be as difficult to find an adequate substitute as it has been in the mammals. The elasmobranchs run a similar gamut from ovoviviparity to viviparity, but no attempts to grow in vitro the embryos of sharks, dogfishes, rays, sawfishes, or guitarfishes seem to have been recorded. On the other hand, the large eggs of the oviparous sharks and skates have proved excellent experimental subjects (Vivien, 1941, 1954).

Whether the eggs and young of the marine fishes that practice oral incubation would be especially suited for laboratory culture is a pertinent question. Shaw and Aronson (1954) and Shaw (1957) have shown that the eggs and young of one of the fresh-water, mouth-breeding cichlids can be cultured outside the parent's mouth. There appears to be no reason why similar techniques would not work with the sea catfishes (family Ariidae), although there might be a problem in feeding the young fish, which are known to ingest food during the latter part of the 2-month period spent in the father's mouth. In the cardinalfishes (family Apogonidae) and jaw-

fishes (family Opisthognathidae), however, the spawn is held together in a single mass, and in the former group at least, the young are not incubated and hatch at an unadvanced stage.

The following bibliography makes no claim to completeness, but it will serve to introduce the investigator to a scattered literature. Those items indicated by an asterisk contain information of general interest and should be consulted no matter what species is to be investigated.

BIBLIOGRAPHY

[Asterisk (*) indicates paper of general interest which should be consulted no matter what species is to be investigated]

ANTHONY, RAOUL L. F.

1910. The cultivation of the turbot. (Translated from the French. Proceedings of the Fourth International Fishery Congress, Washington, 1908) U.S. Bureau of Fisheries, Bulletin, vol. 28, part 2, pp. 859–870.

ATZ, JAMES W., and GRACE E. PICKFORD.

1959. The use of pituitary hormones in fish culture. Endeavour, vol. 18, No. 71, pp. 125–129.

BISHAI, H. M.

1960a. The effect of gas content of water on larval and young fish. Zeitschrift für Wissenschaftliche Zoologie, vol. 163, Nos. 1/2, pp. 37–64.

1960b. The effect of water currents on the survival and distribution of fish larvae. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 25, No. 2, pp. 134–146.

1960c. The effect of hydrogen ion concentration on the survival and distribution of larval and young fish. Zeitschrift für Wissenschaftliche Zoologie, vol. 164. Nos. 1/2, pp. 107–118.

1961a. The effect of salinity on the survival and distribution of larval and young fish. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 26, No. 2, pp. 166–179.

1961b. The effect of pressure on the survival and distribution of larval and young fish. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 26, No. 3, pp. 292–311.

1961c. Rearing fish larvae. Bulletin of the Zoological Society of Egypt, No. 16, pp. 4–29. Arabic summary.

BLAXTER, JOHN H. S.

1960. The effect of extremes of temperature on herring larvae. Journal of the Marine Biological Association of the United Kingdom, vol. 39, No. 3, pp. 605–608.

*1962. Herring rearing—IV. Rearing beyond the yolk-sac stage. Department of Agriculture and Fisheries for Scotland, Marine Research, vol. 1962, No. 1. 18 pp.

BLAXTER, JOHN H. S., and G. HEMPEL.

1961a. Biologische Beobachtungen bei der Aufzucht von Heringsbrut. Helogoländer Wissenschaftliche Meeresuntersuchungen, vol. 7, No. 5, pp. 260–284. (English summary.)

1961b. Rearing experiments on herring larvae. Naturwissenschaften, vol. 48, No. 3, pp. 81–82.

BREDER, CHARLES M., JR.

1922. The problem of marine fish culture. Transactions of the American Fisheries Society, vol. 52, pp. 210–218.

BURD, A. C., and R. JONES.

1948. Rearing of young cod ("Gadus callarias") from an artificial fertilisation at Port Erin. Marine Biological Station, Port Erin, Annual Report for 1945–1947, Nos. 58–60, pp. 36–37. (Casual observations; fish reared in pond.)

CLEMENS, HAROLD B.

1956. Rearing larval scombrid fishes in shipboard aquaria. California Fish and Game, vol. 42, No. 1, pp. 69–79.

COSTELLO, DONALD PAUL, M. E. DAVIDSON, A. EGGERS, M. H. FOX, and C. HENLEY.

*1957. Methods for obtaining and handling marine eggs and embryos. Marine Biological Laboratory, Woods Hole. xv+247 pp.

DANNEVIG, ALF, and GUNNAR DANNEVIG.

*1950. Factors affecting the survival of fish larvae. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 16, No. 2, pp. 211–215.

DANNEVIG, ALF, and SIGFRED HANSEN.

*1952. Faktorer av betydning for fiskeeggenes og fiskeyngelens oppvekst. Reports on Norwegian Fishery and Marine Investigations, vol. 10, No. 1, 36 pp. [English summary.]

Dannevig, Gunnar.
1963. Artificial rearing of cod. Reports on Norwegian Fishery and Marine Investigations, vol. 13, No. 6, pp. 73–79.

Dempster, Robert P.
1953. The use of larval and adult brine shrimp in aquarium fish culture. California Fish and Game, vol. 39, No. 3, pp. 355–364.

Dovel, William.
1960. Larval development of the oyster toadfish, *Opsanus tau*. Chesapeake Science, vol. 1, Nos. 3/4, pp. 187–195.

Gabriel, Mordecai L.
1944. Factors affecting the number and form of vertebrae in Fundulus heteroclitus. Journal of Experimental Zoology, vol. 95, No. 1, pp. 105–147.

Garstang, Walter.
1900. Preliminary experiments on the rearing of sea-fish larvae. Journal of the Marine Biological Association of the United Kingdom, vol. 6, No. 1, pp. 70–93.

Gordon, Myron.
*1950. Fishes as laboratory animals. Pp. 345–449 of The care and breeding of laboratory animals, edited by Edmond J. Farris. John Wiley, New York. 515 pp.

Herald, Earl S., and Maurice Rakowicz.
1951. Stable requirements for raising sea horses. Aquarium Journal [San Francisco], vol. 22, No. 12, pp. 234–242.

Herald, Earl S., Robert P. Dempster, Clyde Wolters, and Marjorie I. Hunt.
1962. Filtration and ultraviolet sterilization of seawater in large closed, and semi-closed aquarium systems. Communications I^{er} Congrès International d'Aquariologie, vol. B, pp. 49–61.

Hertling, Helmuth.
*1932. Die Züchtung von Meeresfischen für wissenschaftliche und praktische Zwecke. Handbuch der Biologische Arbeitsmethoden, Abt. 9, Methoden der Erforschung der Leistungen des tierischen Organismus, Teil 6, Heft 2 (Lief. 395), pp. 195–366.

Heuts, M. J.
1947. Experimental studies on adaptive evolution in *Gasterosteus aculeatus* L. Evolution, vol. 1, Nos. 1/2, pp. 89–102.

Hirano, Reijiro.
1963. On the rearing of larvae of marine animals with special reference to their food organisms. Bulletin of the Japanese Society of Scientific Fisheries, vol. 29, No. 3, pp. 282–297. [In Japanese.]

Holliday, F. G. T., and J. H. S. Blaxter.
1960. The effects of salinity on the developing eggs and larvae of the herring. Journal of the Marine Biological Association of the United Kingdom, vol. 39, No. 3, pp. 591–603.

Kasahara, Shogoro, Reijiro Hirano, and Yasuo Ohshima.
1960. A study on the growth and rearing methods of the fry of black porgy, *Milio macrocephalus* (Basilewsky). Bulletin of the Japanese Society of Scientific Fisheries, vol. 26, No. 3, pp. 239–244.

Kotthaus, Adolf.
1939. Zuchtversuche mit Heringslarven (*Clupea harengus* L.). Helgoländer Wissenschaftliche Meeresuntersuchungen, vol. 1, No. 3, pp. 349–372.

Leiner, Michael.
1934. Beitrage zur ontogenetischen Entwicklung der drei europaischen Stichlingsarten und ihrer Kreuzungsprodukte. Zeitschrift für Wissenschaftliche Zoologie, vol. 145, pp. 366–388.

MacGinitie, G. E.
1947. Sea water systems at marine laboratories. Science, vol. 106, No. 2747, pp. 171–173.

McHugh, J. L., and Boyd W. Walker.
1948. Rearing marine fishes in the laboratory. California Fish and Game, vol. 34, No. 1, pp. 37–38.

Marr, John C.
1956. The "critical period" in the early life history of marine fishes. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 21, No. 2, pp. 160–170.

Marshall, S. M., and A. P. Orr.
1958. Some uses of antibiotics in physiological experiments in sea water. Journal of Marine Research, vol. 17, pp. 341–346.

Morris, Robert W.
1955. Some considerations regarding the nutrition of marine fish larvae. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 20, No. 3, pp. 255–265.
*1956. Some aspects of the problem of rearing marine fishes. Bulletin de L'institut Océanographique (Monaco), No. 1082, 61 pp.

Needham, James. G., Paul S. Galtsoff, Frank E. Lutz, and Paul S. Welch (Editors).
*1937. Culture methods for invertebrate animals. Comstock Publishing Co., Ithaca, N.Y. xxxii + 590 pp. Reprinted in 1959 by Dover Publications, New York.

OPPENHEIMER, CARL H.
1955. The effect of marine bacteria on the development and hatching of pelagic fish eggs, and the control of such bacteria by antibiotics. Copeia, 1955, No. 1, pp. 43–49.

PERLMUTTER, ALFRED.
1961. Possible effect of lethal visible light on year-class fluctuations of aquatic animals. Science, vol. 133, No. 3458, pp. 1081–1082.

QASIM, S. Z.
1955. Rearing experiments on aquatic teleost larvae and evidence of their need for sleep. Nature (London), vol. 175, No. 4448, p. 217.
*1959. Laboratory experiments on some factors affecting the survival of marine teleost larvae. Journal of the Marine Biological Association of India, vol. 1, No. 1, pp. 13–25.

RILEY, JOHN D., and GRAHAM T. THACKER.
1963. Marine fish culture in Britain. III. Plaice (*Pleuronectes platessa* (L.)) rearing in closed circulation at Lowestoft, 1961. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 28, No. 1, pp. 80–90.

ROLLEFSEN, GUNNAR.
1939. Artificial rearing of the fry of sea water fish. Preliminary communication. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-verbaux des Réunions, vol. 109, pt. 3, No. 26, p. 133.

RUBINOFF, IRA.
1958. Raising the atherinid fish, *Menidia menidia*, in the laboratory. Copeia, 1958, No. 2, pp. 146–147.

RUSTAD, D.
1960. Improved rearing of young plaice (*Pleuronectes platessa* L.) by application of penicillin. Kongelige Norske Videnskap Selskabs Forhandlinger (Trondheim), vol. 33, No. 1, pp. 1–4.

SHAW, EVELYN S.
1957. Potentially simple technique for rearing "germ-free" fish. Science, vol. 125, No. 3255, pp. 987–988.

SHAW, EVELYN S., and LESTER R. ARONSON.
1954. Oral incubation in *Tilapia macrocephala;* 2. Experimental studies. Bulletin of the American Museum of Natural History, vol. 103, No. 5, pp. 391–415.

SHELBOURNE, JAMES E.
1956. The abnormal development of plaice embryos and larvae in marine aquaria. Journal of the Marine Biological Association of the United Kingdom, vol. 35, No. 1, pp. 177–192.
1963a. A marine fish-rearing experiment using antibiotics. Nature (London), vol. 198, No. 4875, pp. 74–75.
1936b. Marine fish culture in Britain; II. A plaice rearing experiment at Port Erin, Isle of Man, during 1960, in open sea water circulation. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 28, No. 1, pp. 70–79.

SHELBOURNE, JAMES E., JOHN D. RILEY, and GRAHAM T. THACKER.
*1963. Marine fish culture in Britain. I. Plaice rearing in closed circulation at Lowestoft, 1957–1960. Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 28, No. 1, pp. 50–69.

SHŌJIMA, YŌICHI.
1957. On the development of eggs and rearing of larvae of a puffer, *Fugu* (*Higanfugu*) *pardalis* (T. and S.). Science Bulletin of the Faculty of Agriculture of Kyushu University, vol. 16, No. 1, pp. 125–136.

SIMPSON, DONALD A.
1957. Sea colts in Steinhart's stable. Aquarium Journal (San Francisco), vol. 28, No. 1, pp. 11–15.

SOLEIM, P. A.
1950. "Årsaker til rike og fattige årganger af sild." (English abstract by E. M. Poulson.) Journal du Conseil Permanent International pour l'Exploration de la Mer, vol. 16, No. 2, p. 249.

STRAUGHAN, ROBERT P. L.
1957. Salt water toadfish spawned; babies raised. The Aquarium (Norristown, Pa.), vol. 26, No. 12, pp. 382–385.

STRAWN, KIRK.
1954. Keeping and breeding the dwarf seahorse. Aquarium Journal (San Francisco), vol. 25, No. 10, pp. 215–219.
1958. Life history of the pigmy seahorse, *Hippocampus zosterae* Jordan and Gilbert, at Cedar Key, Florida. Copeia, 1958, No. 1, pp. 16–22.

TRACY, HENRY C.
1959. Stages in the development of the anatomy of motility of the toadfish (*Opsanus tau*). Journal of Comparative Neurology, vol. 111, No. 1, pp. 27–81.

TRINKAUS, J. P., and JOHN W. DRAKE.
1952. Role of exogenous nutrients in development of the viviparous teleost, Lebistes reticulatus. Anatomical Record, vol. 112, No. 2, p. 435. Abstracts of Papers.

TRIPLETT, EDWARD L.
1960. Notes on the life history of the barred surfperch, *Amphistichus argenteus* Agassiz, and a technique for culturing embiotocid embryos. California Fish and Game, vol. 46, No. 4, pp. 433–439.

VIVIEN, JEAN H.
1941. Contribution à l'étude de la physiologie hypophysaire dans ses relations avec l'appareil génital, la thyroïde et les corps interrenaux chez les poissons sélaciens et téléostéens, *Scylliorhinus canicula* et *Gobius paganellus*. Bulletin Biologique de la France et de la Belgique, vol. 75, No. 3, pp. 257–309.
1954. Quelques exemples de l'utilisation du germe et de l'embryon de sélacien das les recherches expérimentales concernant la régulation, les paragénèses, l'organogénèse et la physiologie embryonnaire. Archives d'Anatomie, d'Histologie, vol. 37, pt. 2, Nos. 4/8, pp. 163–174.

WISE, JOHN P.
1963. Bibliography on the biology of the cod, *Gadus morhua*, and related species. U.S. Fish and Wildlife Service, Fishery Bulletin, No. 215, vol. 62, pp. 483–538. (Includes list of 34 references on "Hatcheries, hatching and rearing, techniques.")

WOOD, P. C.
1961. The principles of water sterilisation by ultra-violet light, and their application in the purification of oysters. Ministry of Agriculture, Fisheries and Food, London, Fishery Investigations, ser. 2, vol. 23, No. 6. 48 pp.

ESTUARINE WATER SYSTEMS AT SOLOMONS, MARYLAND

By David G. Cargo

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Abstract.—The novel features of two salt-water systems at Solomons, Md., are discussed. Details of the straight-through rising-pipe supply system, progressing cavity pumps, constant-head trough distribution system, and tank arrangements are included. Drawings of these and other associated details are set forth along with a brief evaluation of the two systems and the maintenance schedule employed. A list of sources of equipment is included.

The sea-water systems at the Chesapeake Biological Laboratory might be more aptly termed estuarine-water systems. At this laboratory, approximately halfway between ocean and fresh water, the problems and advantages of each situation are present in addition to circumstances peculiar to a brackish-water environment. Long-term average values of daily salinity show a seasonal range from 9.9 to 16.9 parts per thousand. Similar temperature values range from 2.7° to 27.8° C.

Our primary aim is to provide an estuarine habitat of limited scope which can be observed and, to some extent, controlled so that laboratory experiments can be performed on a continuous basis. While bringing this habitat into the laboratory, every effort was made to avoid changing the chemical or physical character of the water. We envisioned such facilities for use in live storage or holding of experimental animals, in hatching and raising marine organisms, in studying ecological responses of various organisms to controlled and varying conditions, and in short-term educational display. Our success in providing systems capable of answering all of these needs and aims is yet to be determined.

The sea-water systems in current use at Solomons are of recent origin. Since experienced professional advice was unavailable to us, much of our design embodies ideas and suggestions contributed by scientists at this and at other similar marine laboratories. There are two complete and separate sea-water systems. The first system has been in use about 3 years and is installed at a research storage building and, although simple, is proving an extremely useful and reliable arrangement. This system will be referred to as the "wharf system." The second more recent and much more sophisticated system is located at the main research building and has been in operation for about a year and a half. It is still too early to provide an overall evaluation of its potentialities.

There are several features embodied in both of these systems which may be of interest. These contribute in various ways to make the system work better. In some cases, a simplification resulted; in others, the modifications made the system more

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complex. Although final evaluation is not yet possible, we feel that the general result of our efforts has been encouraging.

I am indebted to many persons of this and other institutions who have assisted us in various ways during the designing and installation of these systems. Particular credit is due Dr. L. E. Cronin, Director of the Natural Resources Institute, for his efforts and perseverance in planning for this invaluable and necessary tool for research.

THE WHARF SYSTEM

The wharf system is a simple, straight-through system utilizing plastic piping and a hard-rubber centrifugal pump. Flowing at 80 gallons per minute, the water, after passing through the pump, flows up a continuously rising supply pipe provided with petcocks at frequent intervals. This rising supply was designed to insure that the pipe remains full despite the level of use. This feature has been found to be very efficient (fig. 1).

The rather rapid flow through the system forced us to provide the terminus with a throttling-type valve to provide increased pressure when needed. This valve was required because, when a petcock was opened, the rapid flow aspirated air into the system instead of allowing water to flow from the petcock. This valve induces sufficient back pressure to overcome this aspiratory tendency. We feel that this valve is a necessary component.

We have found that this system remains virtually free of internal fouling of all types except bacterial. During the warm parts of the year, external fouling requires a cleaning of the foot valve and strainer every 10 days to 2 weeks. During the colder periods of the year, this schedule may be extended considerably. Our treatment involves raising the intake head and scraping and scrubbing the external fouling. We then drain the line and flush it thoroughly with hot (130° to 150° F.) fresh water. This hot water is allowed to remain in the line until it has cooled (about 2 hours). The fresh water is then pumped out after the head has been returned to the normal pumping position in the water. This schedule has been markedly satisfactory throughout the 3 years of operation. Occasionally, the motor of the pump is greased sparingly. The pump has required no maintenance or lubrication since installation.

The main features of this system are installed in a special room which has been designed for the handling of samples—washing, sorting, holding, etc. Incorporated in the construction of the building are underfloor drains, and future expansion of the utility is provided by pipe carriers extended to the outside of the walls so that this same system can be used to supply outside tanks if needed at some future date.

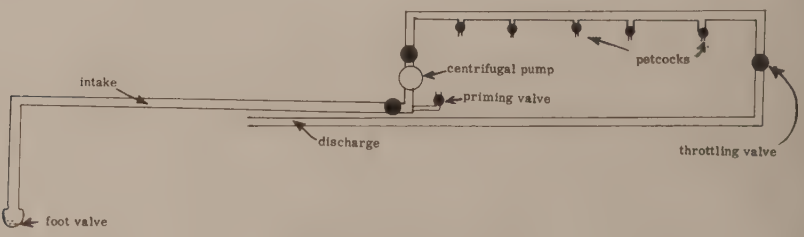

FIGURE 1.—Wharf system.

THE MAIN SYSTEM

The main laboratory research building, about an eighth of a mile from the wharf site, is now supplied with sea water by a dual supply and pump system. The pumps are Moyno progressing cavity units manufactured by Robbins and Meyers. These were chosen in an effort to provide an adequate volume of water with a minimum of change in pressure and turbulence. No metal comes in contact with the inflowing water, and the pumps were specially modified to this end. Each is powered by a 3-horsepower, 230-volt motor, 1750 rpm. The double V-belt drive reduces the pump speed to about 800 rpm.

The stators of these pumps are rubber. The rotors, usually made of stainless steel, are molded of polyurethane. The pumps are further modified by the fabrication of several other parts of nylon instead of stainless steel and by coatings of polyvinyl chloride. The pumps act to entrap successive small volumes of water and push them through the pump with a minimum of turbulence, agitation, or pulsation. Since the entire system is guarded against toxicity from metal and is capable of providing a large volume of water at a relatively low pressure, we expect to be able to conduct a wider range of experiments under conditions which compare favorably with those in the estuary.

Our distribution system in the aquarium room consists of a boxlike trough, suspended from the ceiling joists on brass rods. This trough (figs. 3 and 4) is made of cypress and is coated on the inside with an epoxy-base clear sealer. The divider strip, running longitudinally in the trough, allows a 2-way flow in the trough. The primary aim of this trough is to combine a

FIGURE 2.—Pumproom detail.

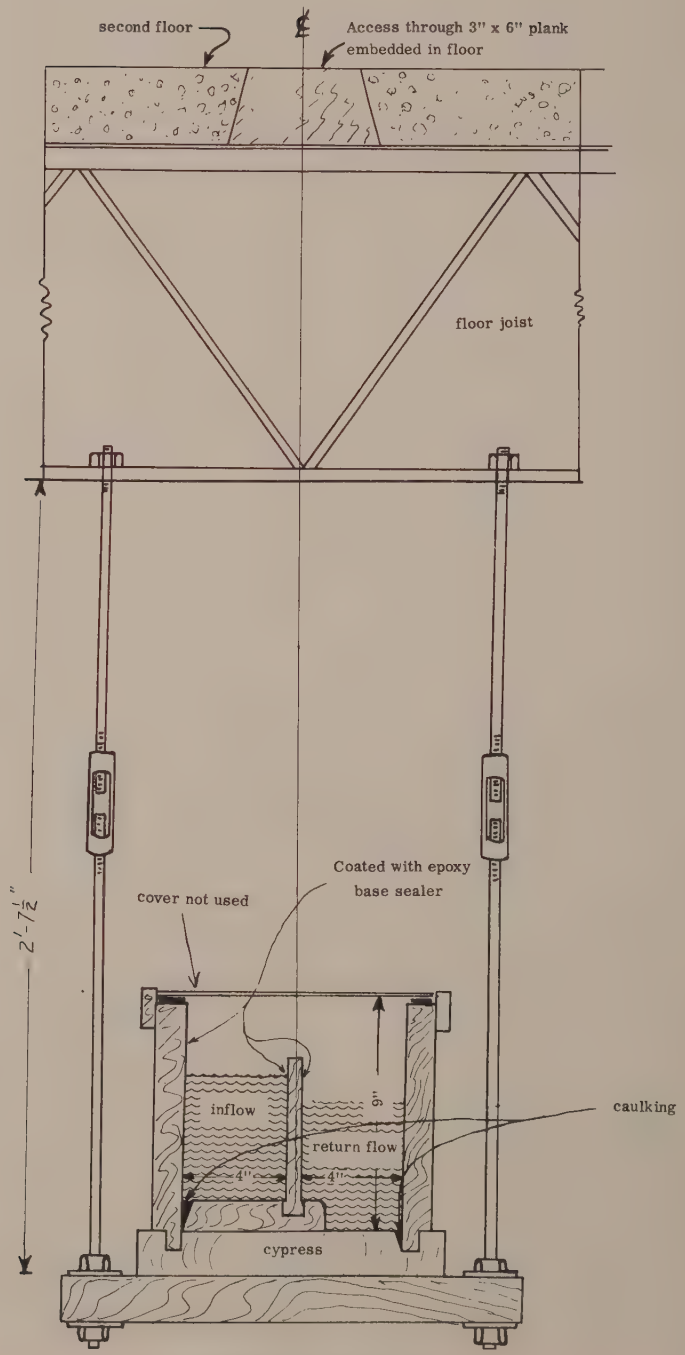

FIGURE 3.—Trough detail.

FIGURE 4.—View of overhead trough showing petcocks.

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simple distribution system with a constant-head supply so that the control of the various taps is not as critical as it would be if it were a closed, pressure-type system. For distribution to the tanks, an undersized hole is bored in the bottom of the trough, a tap is run through the hole, and a hard-rubber petcock is threaded into the hole. Our original design included weirs at several places (fig. 5) which were de-

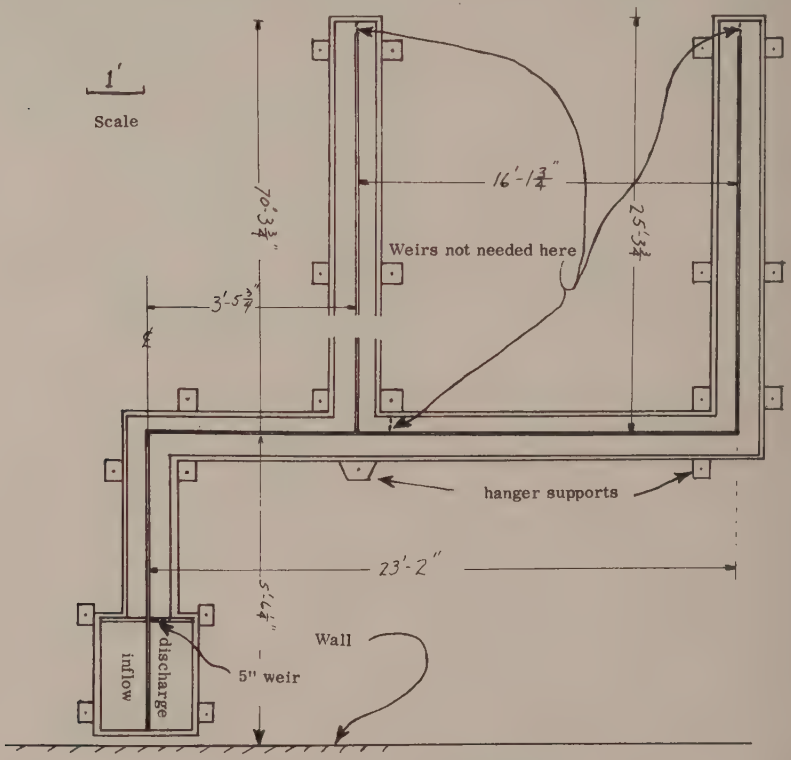

FIGURE 5.—Plan of distribution trough.

signed to maintain a level in the trough. Actually, only the weir at the discharge box is required; the remainder have been removed.

In use, the trough has required a regular scraping and removal of the accumulated fouling. Fortunately, most of this fouling occurs in the first one-quarter of the path that the incoming water travels. Access to the trough from the second floor of the research building is provided by a wooden plank embedded in the concrete floor. Thus, the boring of an access hole is an easy matter.

The aquarium tanks, shown in some detail in figures 6 and 7, have proved very successful. The stainless-steel bolts can be covered with a synthetic-rubber compound. The condensation on the inner walls has not proved bothersome; however, some leakage has been experienced so that the groove for carrying off condensation has seen considerable use. The problem of adequately sealing the glass to the concrete has not been completely solved, but we have not considered the slight leakage worth the effort of resealing these places.

Several other features of the tanks merit

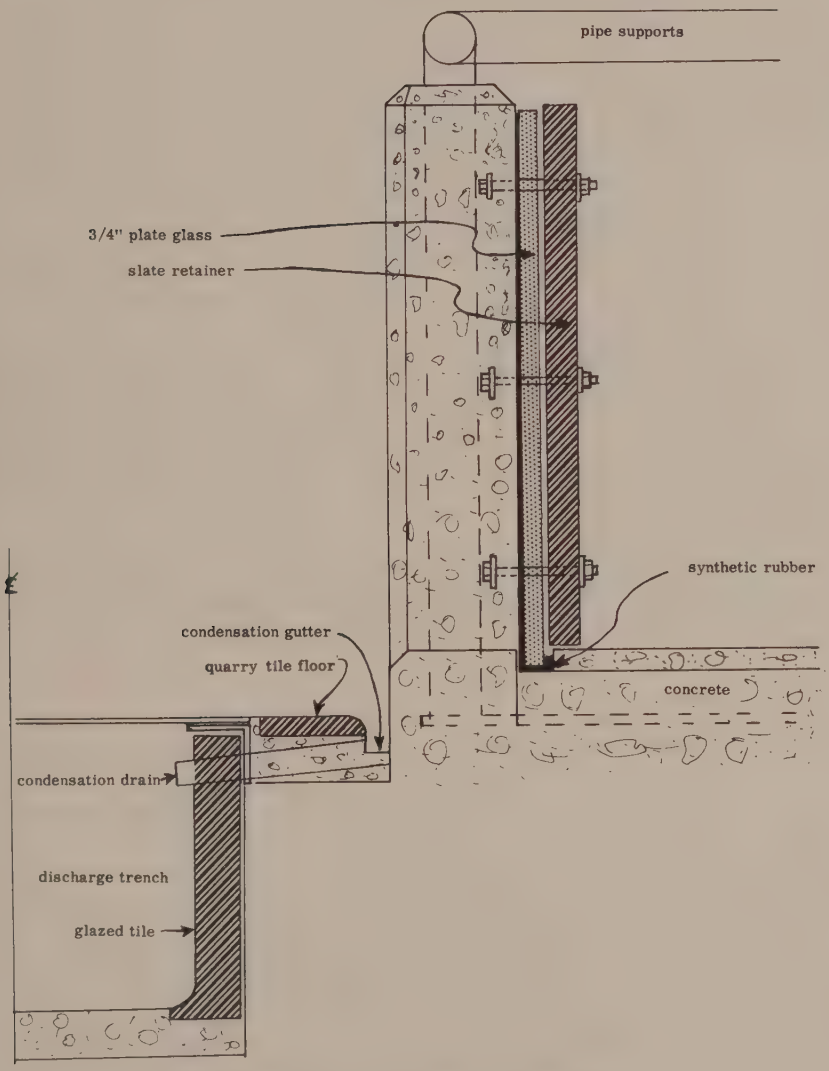

FIGURE 6.—Detail of aquarium construction.

special attention. The heavy pipe supports (fig. 7) are of double-strength pipe, fabricated into one welded framework and galvanized. These supports are designed to serve as a base for other aquariums or tanks, cooling and heating equipment, and monitoring and controlling components. They are heavy enough to support a volume of water comparable to the tank below. Although not obvious in the photograph, the glass partitions between the tanks are held in place with replaceable packing and are removable. This feature permits us to expand the size and utility of these tanks. We have employed 3-inch standpipes of PVC plastic in these tanks which allows us to adjust, through the use of plastic pipe plugs, the height of the

FIGURE 7.—General view of aquariums.

water in the tanks. These plugs are threaded into holes tapped into the sides of the standpipes.

The entire pumping system (fig. 8) is flushed regularly with fresh water held in a 500-gallon tank and coupled into the system. This water is not heated. Some minor fouling occurs inside the foot valve but has not proved troublesome. This same backwash water is used for priming the pumps when necessary. Naturally, this fresh water is not allowed to enter the supply trough when purging the lines.

A feature common to both systems is a strainer which is necessary to avoid the clogging of the intake by jellyfish and ctenophores. After trying several designs, we found that a large polyethylene wastebasket pierced by numerous ¼-inch holes and attached to a wooden disk clamped to the intake pipe answers this need nicely. By releasing two bolts (we used plastic bolts), the unit can be disassembled and scrubbed. The wooden disk was not painted but is still in good condition after 18 months' use. In general, this screen arrangement has proved very efficient and satisfactory.

EVALUATION AND REMARKS

The wharf system has provided us with an extremely reliable source of running water for a period of almost 3 years. Initial problems with priming and the strainers were quickly resolved as our familiarity with the equipment increased. The entire system was installed by our maintenance staff at the site; installation required no outside assistance.

The main research system has given problems which might be considered commensurate with the complexity of the system. Certain mechanical failures have resulted, principally from unfamiliarity

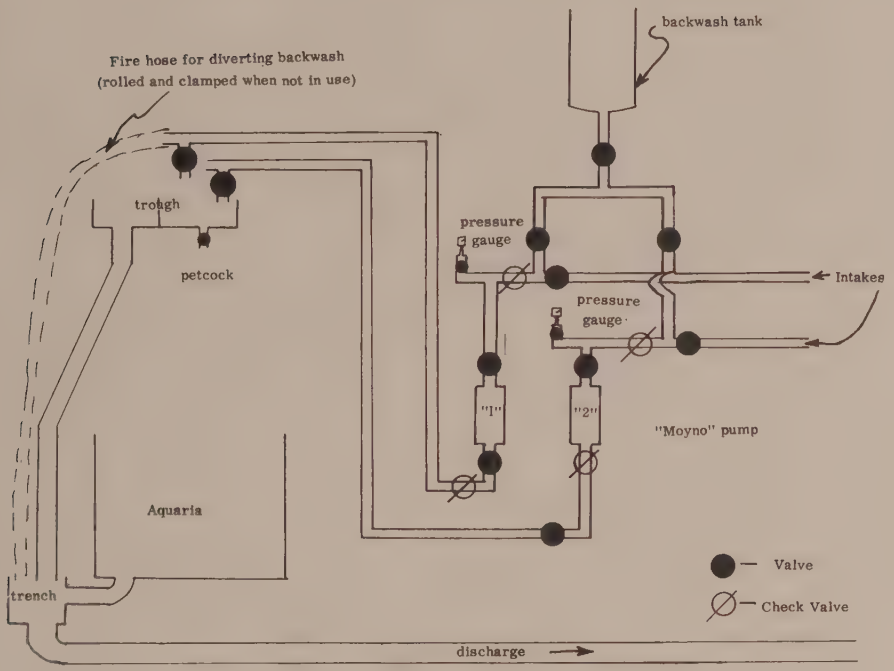

FIGURE 8.—Main system (dual).

with the equipment and a lack of adequate manufacturers' instructions concerning maintenance requirements. It is felt that our present schedule will enable us to operate on a more satisfactory basis.

Our aim of producing water at a low pressure was answered in a most heartening manner when numbers of small medusae of *Chrysaora q. quinquecirrha* were observed swimming in several of the tanks. These were about 1 to 1½ inches in diameter and appeared to be in excellent condition. Since that time, practically all of the local larval forms have passed through the pumps successfully and most have metamorphosed in the trough or tanks. Thus, our present feeling is that these pumps are worth the effort and expense.

We have had several failures due to circumstances which could not be counteracted at the time of their occurrence. It is therefore strongly recommended that a safety switch and relay be made a part of any system so that a stoppage or slowing of the water flow for any reason will shut off the pump, thus protecting the unit from serious damage. Of equal importance is the provision for thermal overload protection for each motor. We recently lost a motor because of a low-voltage condition which caused the field windings to overheat and short-circuit.

The following is a list of suppliers of the components we have used in our system.

Centrifugal pumps: American Hard Rubber Co., Butler, N.J.

Moyno pumps: Robbins & Myers, Springfield, Ohio.

PVC and hard-rubber valves, pipe, fittings: American Hard Rubber Co., Butler, N.J.

PVC and hard-rubber valves, pipe, fittings: Vanton Pipe and Equipment Co., Hillside, N.J.

Polyethylene piping, fittings: American Hard Rubber Co., Butler, N.J.

Polyethylene piping: Sears, Roebuck & Co., Philadelphia, Pa.

Polyethylene piping and fittings: Yardley Plastics, Columbus, Ohio.

Vinyl and polyethylene tubing and containers: Phipps & Bird, Inc., Richmond, Va.

Epoxy-base paint: Pettit Paint Co., Belleville, N.J.

Black asphaltum varnish: Devoe & Raynolds Co., New York, N.Y.

Pressure switches: Barksdale Valves, Los Angeles 58, Calif.

Stainless-steel pipe clamps: Murray Co., Towson, Md.

SUMMARY

The two systems for supplying salt water for the Chesapeake Biological Laboratory at Solomons are essentially metal-free, continuous-running systems. One provides 80 gallons per minute through a centrifugal pump, the other 25 gallons per minute through a progressing cavity pump at a low pressure. The first is a straight-through, positive-pressure unit of simple design. The second is more complicated, with a novel and efficient distribution system.

Both of these systems have their advantages and disadvantages but present experience indicates that an increased efficiency and utility will be realized in the future as our familiarity with these units is improved.

REFERENCES

MacGinitie, G. E.
1947. Sea water systems at Marine Laboratories. Science, vol. 106, No. 2747, pp. 171–173.

Mairs, Donald F.
1961. Toxicity of an epoxy cement to fishes. Progressive Fish-Culturist, vol 23, No. 4, p. 178.

Townsend, Charles Haskins.
1928. The public aquarium; its construction, equipment, and management. U.S. Bureau of Fisheries, Report of the U.S. Commissioner of Fisheries for 1928 (Appendix VII), pp. 249–337.

SEA-WATER SUPPLY IN THE TROPICS

By Warren Wisby

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Abstract.—The existing sea-water system is described for institutions in need of a moderate supply of sea water. Special methods were devised to eliminate frequent maintenance, save space, accommodate an extremely high ground-water level, and permit continuous operation in spite of tropical storms. Additions and changes for a contemplated enlarged facility are discussed, covering the control of temperature, salinity, pH, dissolved oxygen and CO_2, and turbidity in the incoming water. Methods are given whereby programed variations of any controllable parameter may be maintained.

When, some months ago, a new laboratory was being planned for the Institute of Marine Science of the University of Miami, the existing salt-water pumping system was subjected to intensive scrutiny and examination to determine which of its features were generally deemed worth retaining and which were to be improved or discarded. The experiences of our staff members in various marine laboratories, in this country and abroad, were drawn upon. Conferences were held with experts from various disciplines, including biologists, corrosion engineers, chemists specializing in toxicity studies, and hydraulics engineers. The plans which resulted from this search and evaluation program retained many features of the existing system. In the belief that a description of the existing system would be of value to institutions with moderate sea-water demands, it will be described in the first portion of this paper. The remainder of the paper will describe the contemplated system in detail.

EXISTING SYSTEM

The salt-water supply system now in use in the Agassiz Building of the Institute of Marine Science was installed when the Institute's laboratory facilities were moved to their present location on Virginia Key in 1953, and has been in continuous use since that time. A few relatively minor changes have been made in the system; these were due mainly to an increase in the demands placed upon it by a greatly expanded scientific staff. When, some years later, a second salt-water laboratory was planned, it was decided that the existing pumping and distribution systems had proven their worth, and a duplicate system was installed in that facility, now our Collier Building. These two similar systems have managed to provide the entire supply of salt water for the Institute until the present time when, again because of increasing demands, they were judged inadequate and plans for a new salt-water facility were started. The simplicity of their design recommends them primarily for small installations. However, many of their design features should, and can, be incorporated into more extensive systems.

The Institute of Marine Science is on Virginia Key on the shore of Bear Cut, a narrow strait connecting a shallow part

of Biscayne Bay with the Atlantic Ocean. Water conditions in Bear Cut vary from relatively clear water free of suspended materials, on an incoming tide, to rather turbid water with a silicaceous silt load on an outgoing tide. Turbidity increases when winds are high and especially when high winds are combined with spring tides.

The intake for the present salt-water system is fastened to the laboratory pier and consists of a screened foot valve, which is easily removed for cleaning, within a sturdy box which is itself fitted with easily removable, coarse, stainless-steel screening. The foot valve is located about 6 feet under the surface of the water at mean tide, placing it about the same distance over the bottom. The intake line, about 50 feet in length, is composed of 3-inch black polyethylene pipe and leads to a manifold which is connected to the suction side of two Jaeger centrifugal pumps, each of which is powered by a 3-phase, 1-horsepower motor. The pumps have a rated capacity of 50 gallons per minute under these operating conditions and are so valved that either pump can be placed in service. The initial cost of these pumps is remarkably low, and it is therefore feasible to keep standby units on hand. Furthermore, repairs are not costly and are, as a matter of fact, infrequent. This type of pump is commonly used in construction work, and repair facilities should be available in most cities. Repairs have usually consisted in replacement of worn impellers and an occasional volute, neither of which requires a large expenditure of funds or of time since the pump can easily be loaded into an automobile and taken to the repair shop.

The discharge line is also manifolded at the pumps and is also composed of 3-inch black polyethylene pipe, which has been covered with aluminum paint so as to reduce absorption of heat by the water. This line empties into one end of a concrete tank (10-by-10-by-2-feet) situated on the roof of the building. Here the flow is diffused over a maximum cross section and rendered relatively nonturbulent, by means of removable baffles, in order to reduce the rate of linear flow so that most of the settleable materials are removed. The water level is maintained by means of an electric float switch which controls that pump which happens to be in service. The tank is equipped with a hinged cover to exclude sunlight and accompanying algal growth, and a removable overflow drain which leads back to the bay. Removal of the overflow standpipe allows the settled materials to be flushed and the tank to be cleaned.

The secondary, or distribution, system leaves through a screened outlet located a few inches above the tank floor. It is constructed of the same kind of pipe as are the suction and primary discharge lines. Branches of this system travel down each side of the building for final distribution to the water tables and aquariums. In no case does any pipe have a blind, capped end. Rather, the end of each pipe is fitted with a valve and a discharge line which leads back to the bay, so that the accumulation of sediment, with resultant formation of H_2S, can be prevented by frequent flushing of all parts of the system. The same arrangement is provided in the smaller lines which supply the individual aquariums. Also it was found that sedimentation ceased to be a factor in clogging of valves, which are all of plastic (PVC), if the lines which supplied the aquariums, as well as the plastic stopcocks from these lines, were connected to the upper side of the distribution line instead of the bottom, as is usually the case.

The water tables are constructed of fiberglass-covered plywood, are standardized as to size and design, and are easily movable. Each has two levels which are

supplied with running sea water, and each level is connected by a drain hose to a gutter which carries the waste back to the bay.

The feature of the distribution system which is considered to be the most important is that nowhere in the entire system is an elbow joint used. Where it is necessary to turn a corner, a four-way fitting is used and the unwanted openings are capped. Thus, any section of pipe can be thoroughly cleaned with a plumber's "snake" merely by removing the cap that leads in a straight line to the proper section. We have found through experience that such cleaning must be part of the regular maintenance schedule owing to the rapid growth of settling organisms in the tropics.

SALT-WATER SYSTEM FOR NEW BUILDING

The sea-water system designed for the new laboratory remains relatively unchanged from this original concept. It will, of course, be much larger and more sophisticated as to controls, but the basic principles have been judged sound and time-tested and will be adhered to. All primary and secondary piping will be of PVC plastic, including the valves, and will be installed in duplicate down to the final distribution level. Provisions will be made to keep unused portions filled with fresh water to destroy any marine organisms which may have settled during their periods of use. Our experience has shown that if this is done bimonthly, the majority of settling organisms will be so small that the calcareous shell will be removed from the walls of the pipe when the organism dies. Provision will also be made for flushing the used portion of the system with a fast flow of sea water daily, thus preventing sediment from accumulating in the piping in use.

The question of filtration was again examined in detail and the conclusion was the same as that arrived at when the existing system was planned—that a settling tank on the roof was most suited to our needs. Our water supply was first subjected to scrutiny. It was found, by drilling test wells, that our underground salt water, although crystal clear, contained so much dissolved H_2S as to render it unsafe for use with small marine organisms, even after treatment. Also, while it might be possible to maintain living fishes in this treated water, whether they could then be considered "normal" in activity and in behaviour is questionable.

Mechanical and biological filters were also discussed and discarded; the former because of the difficulty of cleaning and the frequency with which this would be necessary with our water conditions, and the latter because of the undesirable contribution of additional larvae and eggs to the already present problem. It was also decided that the settling tank should be on the roof, as at present, for several reasons. First, pressure systems, the other alternative, are not satisfactory in the tropics because of the danger of supersaturation of dissolved gases with even slight warming of the water, with resultant trauma to the tissues of the experimental organisms. Second, our ground water is so near the surface as to make digging difficult. Third, a large underground tank would have to be kept filled with water in order to prevent its "floating," especially in the event of storm flooding, and this would make cleaning difficult. Fourth, a ground surface tank would take up valuable space and would necessitate two sets of pumps, one to pump into the tank and one to pump from the tank to the roof of the building, where a gravity tank would be installed.

Tests were again conducted on the rate of settling of the materials suspended in the intake water, and it was found that a

retention time of 90 minutes was sufficient for the large majority of our experiments. The tank was therefore designed to provide a retention time of 1½ hours at the maximum pumping rate of 36,000 gallons per hour. It will cover most of the roof of the building and will be shielded from the direct rays of the sun by a permanent cover, which also acts to prevent dilution by rain water.

Provision has been made for cleaning by dividing the tank into two parts. Either part can function as a settling tank while the other is shut down. The settled water will be collected in a sump at the end of the tank for final distribution to the laboratories. This will ensure a constant head of water to the secondary piping system. In many cases this water will require no further filtration. Nevertheless, unit filters will be generally available, to be used or bypassed as desired. The filter units are plastic, with disposable filter elements, and are similar to those successfully used elsewhere. The cost of the elements is relatively small, they can be obtained with various pore sizes, and should last from 2 to 3 days in an average installation before cleaning or replacement is needed.

Many of the problems of a salt-water system have to do with the corrosive nature of the sea water, while others are due to the erosive effects of suspended materials. A search was instigated to find a pump which would resist the effects of both of these factors. The investigation has narrowed down to a centrifugal pump with a special rubber lining. A total of three pumps will be installed in parallel connection. The pumps will be actuated automatically by a demand signal from a float-type switch sensing the water level in each distribution sump. As many pumps will be in operation as are required to maintain the desired head of water.

As in our present sea-water system, all piping will consist of straight runs without bends or elbows. Four-way fittings, or tees will be used at all corners so that a cleaning rod can be inserted easily. It is planned to use unplasticized nontoxic PVC piping both in the primary and in the secondary distribution systems. All valves will be of similar inert materials, either PVC, Teflon, or hard rubber, depending upon their size. Automatic control systems will be provided for regulating the following environmental parameters. (See Addendum on p. 118.)

Temperature

A number of thermostatically controlled, portable units for heating and cooling the settled sea water will be available for individual use.

Salinity

Water conditioning will take place in a mixing chamber before being introduced into the aquariums. Salinity levels will be sensed by means of a conductivity cell, or inductive type cell, and automatic regulation applied to the inflowing water supply. Salinity will be reduced by the metering in of distilled water or of fresh water previously passed through a dechlorinator. Salinity will be increased by spraying raw salt water into an evacuated chamber with subsequent reoxygenation. A salinity control of $\pm$ 1 part per thousand can be provided.

pH

Adjustment of pH will take place in a tank before the sea water enters the aquariums. Measuring electrodes will be glass (Beckman) with a calomel reference. The measured values will actuate the control system so that an acid or a base will be metered into the mixing tank at a rate sufficient to maintain the desired pH.

Dissolved oxygen

Measurement and recording of the dissolved oxygen will be accomplished with either Kanwisher or Beckman type elec-

trodes. Oxygen level may be set and maintained at any desired level between O and saturation. Deviations of the measured level from the present level will provide the control signal for adjusting the oxygen level in the incoming water supply. Oxygen will be added to or removed from the water by passage through a column of glass beads into which oxygen or nitrogen is metered.

Dissolved carbon dioxide

Measuring and control systems similar to those provided for oxygen will be supplied. Carbon dioxide will be added to or removed from the sea water by trickling through a glass bead column into which carbon dioxide is metered or CO_2=free air is passed. An adjustment of pH will be made along with the regulation of carbon dioxide.

Turbidity control

Measurement of turbidity will be made by absorption of light as compared to a neutral density filter. Filters of a wide range of optical density may be inserted into the reference optical path of the control system, and turbidity can then be automatically maintained at a level of equal light absorption. Increase of turbidity can be accomplished by metering in a suspension of the material under study or of some natural sediment into the incoming water supply, or it can be decreased by filtering. The type of material to be used will depend on whether visual effects or effects of sedimentation on bottom organisms are being investigated.

System for maintaining programed variations of any controllable parameter

This system will consist of a graphic recorder and controller which will follow a curve previously plotted on the chart paper. Any desired fluctuation of a variable (as a function of time) can be plotted on the chart paper by hand. As the graphic record is played back, the stylus is made to follow the excursions of the plotted line while at the same time producing a control signal which is a function of its lateral displacement. The control signal is used to regulate the environmental parameter so that it follows directly the preplotted graphic record. The time scale may be synchronized with real time if desired. Fluctuations in such variables as temperature, salinity, or light may be provided in a cyclic manner so that tidal or diurnal cycles are simulated. Nondyclic variations may be programed in the same manner.

SUMMARY

The following problems, some of which are peculiar to the tropics, have been dealt with in the design of the new sea-water system:

1. Sedimentation and growth of fouling organisms in the pipes by (a) filter screens at intake, (b) duplication of all pipelines from intake to final distribution lines, (c) provisions for daily flushing of all pipes, (d) continual flushing of sediments from settling tank, (e) final distribution lines and petcocks leave from the upper sides of secondary supply lines, and (f) use of straight runs of pipe with no elbows.

2. Air embolism in experimental animals, by (a) use of a gravity system of sea-water distribution, and (b) avoidance of temperature increases by continual flushing of water from the storage tank and by insulating the tank from direct sunlight.

3. Toxicity to experimental animals, corrosion, and erosion, by (a) use of nontoxic plastic pipe and valves, and (b) use of rubber-coated pumps.

We believe that this facility, when completed, will be an important addition to the nation's research facilities. The intensive planning which has resulted in the final flexible design, both of the laboratory

and of the sea-water system, should produce a marine, controlled-environment laboratory that will be as useful and convient for scientists of the future as for those of us who will be fortunate enough to use it today.

ADDENDUM

Since this was written, the new installation has been made with duplicate intake and distribution systems. Valves are so arranged that one of the alternate systems is allowed to remain at rest, filled with salt water for a period of 1 or 2 weeks, more than sufficient to kill attached organisms, through anoxia. At the end of this period, the stagnant water, with the remains of dead organisms, is flushed out with clean sea water, and the system is returned to service. Lack of sufficient experience prohibits any statement on successful performance. In the unlikely circumstance that this procedure does not reduce attached growth, provision is made for the introduction of either fresh water or chlorinated water into the resting system.

SALT-WATER SYSTEM AT THE U.S. BIOLOGICAL LABORATORY, BEAUFORT, NORTH CAROLINA

By G. B. Talbot, *Director*

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Abstract.—In conjunction with the construction of a modern laboratory at Beaufort, N.C., a new salt-water system was built, since the one in existence, an aged pump-and-tank intermittent facility, had proved inadequate. The system chosen was a continuous-flow type, installed in duplicate, utilizing a 3-horsepower centrifugal pump, flexible polyethylene pipes, and hard-rubber valves. Indoor water tables are constructed of cypress planks lined with sheet lead and of ¾-inch plywood covered with fiberglass. Outdoor tanks are of concrete and may be divided into four compartments by screen partitions. The system has been in continual use since 1955 and provides an uninterrupted flow of salt water, at constant pressure, regardless of valve actuation.

In 1953, with the prospect that a new laboratory was to be constructed at this station to replace the old structure built in 1901, it became necessary to design a new salt-water system for proposed laboratory experiments. The system then in use consisted of a wood tank located on the upper floor of a 2½-story building, and a cast-iron pump with iron pipes and brass valves which supplied salt water intermittently as needed. Since pumping occurred at irregular intervals regardless of the tide, the salinity was apt to change abruptly at each pumping cycle. While this salt-water supply was useful for some purposes, the method of filling was far from satisfactory and the system often drained dry. In addition, the materials used in the construction of this facility were toxic to some marine organisms.

An auxiliary system, consisting of a pump and pressure tank similar to a shallow-well domestic water pump was used, but it had the same disadvantages as the main system, and in addition most marine organisms in the incoming water were killed in the pressure tank. This necessitated cleaning the tank regularly because of the accumulated debris and silt.

Most of the marine stations along the east coast of the United States were visited in an attempt to determine the faults and virtues of existing salt-water systems. In general, the two kinds in use were intermittent and continuous-pumping types. The former has an advantage in that the salinity can be held more or less constant by using an interval timer to regulate the pumping to a definite part of each tidal cycle. In this system a storage tank of sufficient capacity to furnish salt water for all needs for about 12 hours, less pumping time, is necessary. With the continuous-flow system no storage tank is necessary, but tide-linked variations in salinity of the water source cannot be offset by controlled pumping. The choice of systems depends partially upon location

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of the laboratory in relation to the source of salt water and upon the type of experiments to be conducted.

One major fault found in some continuous-flow systems was that no provision was made to maintain constant pressure when different amounts of water were used. As a result, if small quantities of water were being used in the laboratory and a large valve was opened at an outside tank, pressure in the system dropped to such an extent that water ceased to flow in the laboratory, and it was necessary to further open the spigots in the laboratory to obtain a flow. Then if a valve at an outside tank was closed, pressure in the laboratory increased sufficiently to disrupt experiments in progress. As a result extreme caution had to be observed at all times when valves were opened or closed any place on the system.

Only two really satisfactory nontoxic materials for handling salt-water were found in use in 1953—hard rubber and lead. Some experiments were being carried out with plastic pipe, however, which gave indications that this material would be superior. Since plastic pipe was much more economical to purchase and install than hard rubber and lead, experiments were carried out at this laboratory with several brands of polyethylene and polyvinyl-chloride pipe to determine their toxic effects on marine organisms. Some brands appeared to have an initial toxicity, but after being washed for several hours, none exhibited any toxic properties.

Several pumps were available which had performed satisfactorily on other salt-water systems examined. These were manufactured specifically for handling brines, acids, alkalis, and other corrosive liquids for industrial applications. Construction was of hard rubber or of cast iron lined with rubber so that the liquid being pumped did not come into contact with the metal.

The salt-water system as constructed at this laboratory is a continuous-flow type (shown schematically in figure 1) which was installed in duplicate so that one unit can be used while the other is being cleaned. The dual system also is used to advantage to provide a standby in case of failure in one system. The pump is a 3-horsepower hard-rubber centrifugal type which furnishes 80 gallons per minute at a total head of 30 feet. The same pump is also manufactured in a 1-horsepower model which pumps 40 gallons per

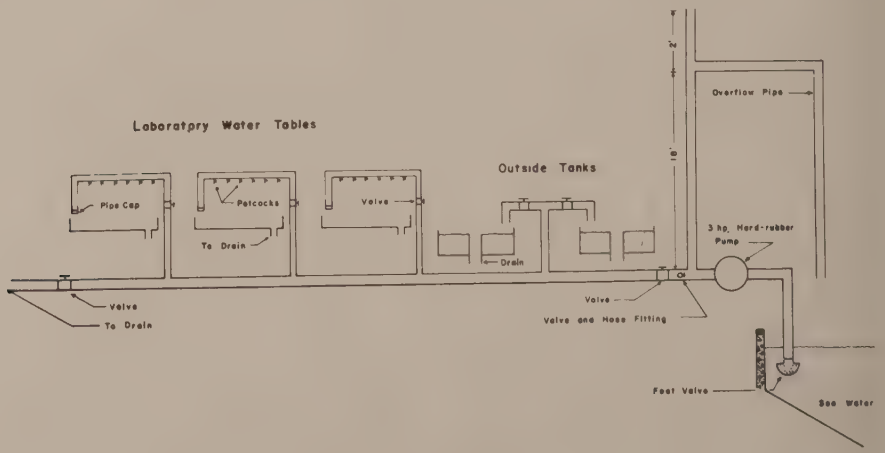

FIGURE 1.—Salt-water system.

minute at the same head. All pipes are 2-inch flexible polyethylene plastic except at laboratory water tables and outside tanks. Here semirigid plastic pipe is used since it can be tapped for petcocks at the water tables and is self-supporting at the outside tanks. One-inch pipes are used at the laboratory tables, and at the outside tanks 1½-inch pipes are used. The foot valve and pipeline valves are of rigid plastic with polyethylene diaphragms.

An overflow standpipe 18 feet at top elevation above the pump maintains constant pressure in the system regardless of how much water is being used, within the capacity of the pump. Excess water flows from the top of the standpipe, and as long as some water is overflowing, the pressure at all outlets at tanks and water tables remains constant regardless of where valves are opened or closed. The top elevation of the standpipe is 12 feet above the highest outlet on the system. Of course, if outlets at higher elevations are desired, such as in a second-floor laboratory, the height of the standpipe would have to be increased to above the outlet height to increase the pressure so that water would rise to the higher elevation. In our installation the top of the standpipe is extended 2 feet above the overflow pipe to accommodate surges of water when the pump is first started.

Hard-rubber pumps must not be allowed to run dry, as this will ruin the pump shaft and seals. Therefore, as a safety precaution a pressure-operated switch is inserted in the electrical power lines to the pump so that it will be stopped automatically if water is not being pumped. This has proved useful many times when the foot valve has become clogged, as by a piece of plastic sheeting, and also has prevented the pump from restarting when the pump and lines have drained dry after a prolonged power failure.

To facilitate the pumping operation when the lines are empty, a valve with a fitting to which a garden hose can be attached is located near the standpipe. The standpipe, pump, and suction line can then be filled with fresh water from a near-by fresh-water spigot before starting the pump.

Since this system is nontoxic to marine organisms, considerable growth occurs within the plastic pipes, thus reducing the amount of water that is transported. The rate of fouling of salt-water systems probably depends upon latitude of the installation and local conditions. In this area it is necessary to clean the system about twice a year. This is accomplished by stopping the pump and allowing the water to remain in the system for about a week until all organisms are dead. Soft forms usually can then be flushed out by starting the pump, opening all valves and drains, and removing pipe caps from the supply at the water tables.

About once a year the setting of hard-shelled animals, such as oysters and barnacles, clogs the pipe to such an extent that acid must be used to dissolve or loosen them. Commercial hydrochloric acid diluted to about 10 percent (1 part acid, 3 parts water) is introduced into the standpipe, and all outlet valves are opened slightly until the dilute acid reaches all parts of the system. The acid solution is allowed to remain in the pipes for approximately 48 hours and the pipes can then be flushed clean.

The outside tanks are made of concrete with inside measurements of 6 feet by 16 feet with depth of 30 inches at the ends and 31 inches near the center (figs. 2 and 3). Notches on the sides allow vertical screen partitions to be inserted so that the tank can be divided into four compartments. A 4-inch pipe nipple cast into the bottom accommodates standpipe over-

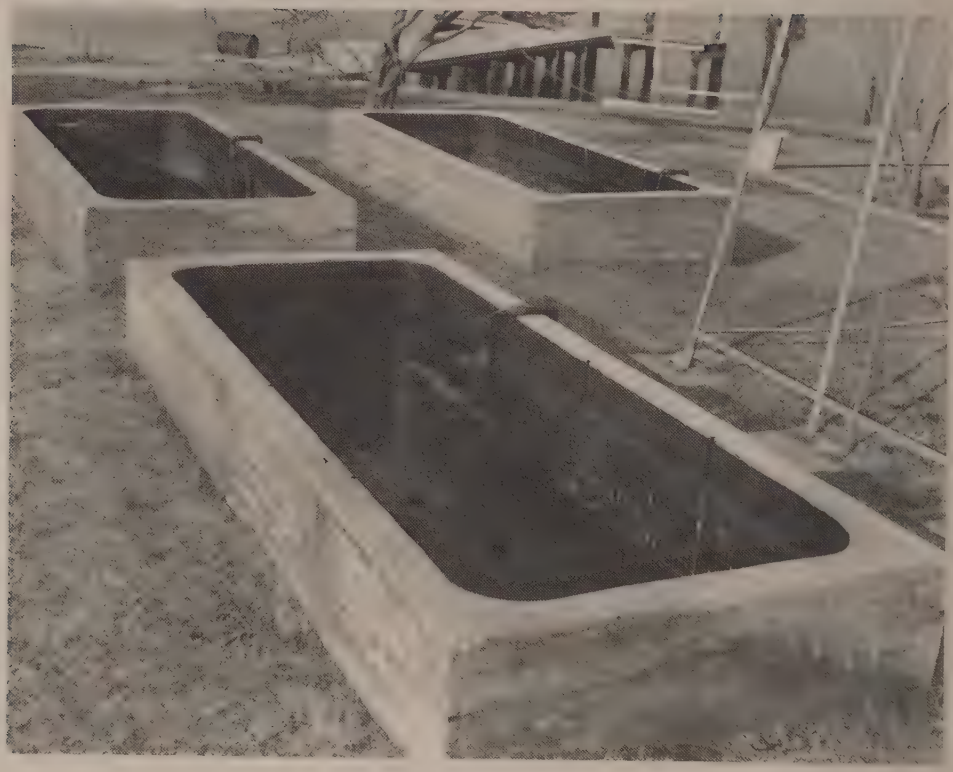

FIGURE 2.—Outside tanks.

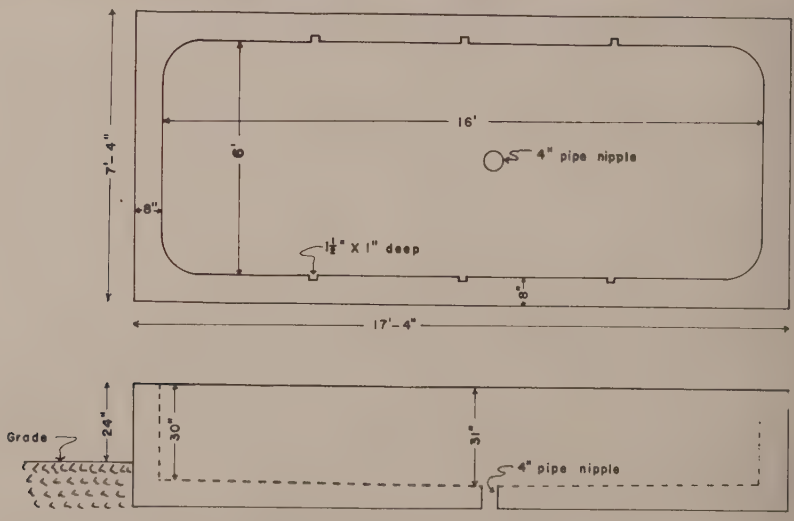

FIGURE 3.—Plan (at top) and cross section (at bottom) of outside tank.

FIGURE 4.—Laboratory water tables with dual salt-water systems.

flows of various heights. The drains from the outside tanks and laboratory tables are of 8-inch terra-cotta pipe with cemented joints.

The water tables in the laboratory, with inside dimensions of 4 feet by 8 feet by 10 inches deep, are constructed of 2- by 10-inch cypress planks and are lined with sheet lead (fig. 4). More recently, additional water tables were constructed of ¾-inch plywood lined with fiberglass. Both types have proved satisfactory. All salt-water pipes as well as other utility lines in the laboratory are located in trenches with sheet iron covers at floor level so that they are readily accessible in case repairs are needed and also to allow flexibility in arrangement of equipment.

This salt-water system has now been in almost continuous operation for more than 7 years and has given excellent service.

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SALT-WATER SYSTEM AT THE ST. ANDREWS BIOLOGICAL STATION OF THE FISHERIES RESEARCH BOARD OF CANADA

By D. S. Mann, D. W. McLeese, and L. R. Day

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Abstract.—Submerged stainless-steel and aluminum-alloy pumps supply salt water through nontoxic plastic piping and fittings to laboratory facilities, and to a 30,000-gallon header tank through a partially effective antisurge unit. Straight runs and T-joints in piping facilitate cleaning. Hot salt water for blending in temperature experiments is produced in a stainless-steel heat exchanger in an oil-fired fresh-water boiler. Expansion valves at compressed-air pumps prevent toxic ions from passing through the copper air-distribution system.

The salt-water system at St. Andrews, New Brunswick, is used to meet various requirements of fishery research, ranging from the culture of planktonic forms to studies of the growth and behaviour of commercial-sized species (fish, crustaceans, mollusks) in controlled environments.

THE SALT-WATER SUPPLY

The station is located where the estuary of the St. Croix River empties into Passamaquoddy Bay and has unlimited access to natural sea water. Each year, the level of diurnal high tides ranges above normal low water from 19 feet during neap tides to 28 feet during spring tides. Water temperatures range from about 32° F. (0° C.) in winter to a maximum of 55° F. (13° C.) in summer. Salinity normally ranges around 28 to 31 parts per thousand although it may fall to 25 parts per thousand during spring runoff. The oxygen content of the sea water is normal.

THE SALT-WATER SYSTEM

The salt-water intake is on the outer face of the station's wharf, approximately 18 feet above the sea bed and 4 feet below the lowest low-tide level. Unfiltered salt water is pumped to a 30,000-gallon concrete reservoir tank about 40 feet above the main laboratories. This elevation provides a constant pressure head for the system. From the reservoir tank, water is distributed to the laboratory buildings (fig. 1). There are facilities to heat part of the supply but no facilities for refrigeration (fig. 2).

Pumps

Two intake pumps, each of 100 gallons per minute capacity, are in use. They are submersible, "Flygt" model B–80L pumps, manufactured by the Stenburg Corporation, Stockholm, Sweden. These pumps are constructed of a salt-water-resistant aluminum alloy with a stainless-steel impeller. Experience has shown that stainless steel is less subject to corrosion and breakage than cast iron. Because the pumps are submerged, leaks at the suction end, which can cause the water to be supersaturated with gases, are avoided. The two pumps have been in use since 1958—one pump in use while the other was being

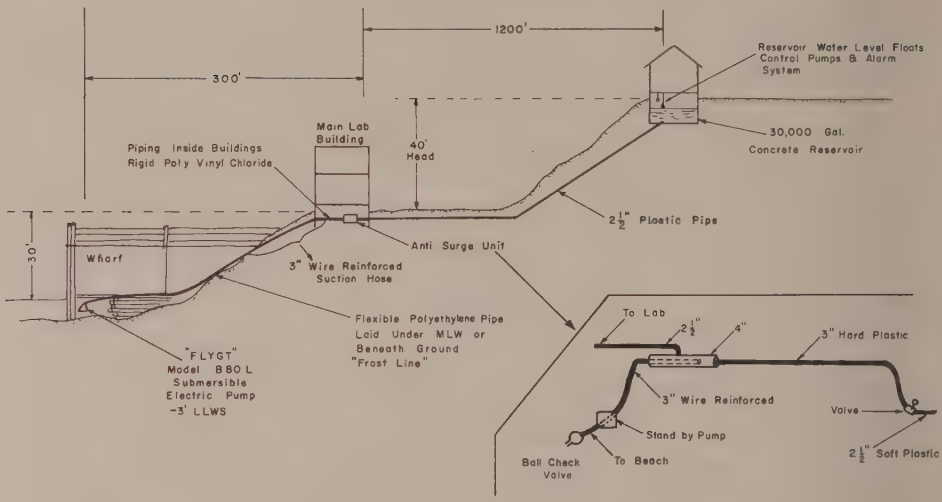

FIGURE 1.—Salt-water system at St. Andrews, N.B., with insert of antisurge unit.

serviced or held in reserve as a standby. Normally the pumps are interchanged on a 6 months' basis. In case of breakdown, pumps can be replaced in less than 1 hour by two men at the first low tide. A 3-inch line from the pump joins a single 2½-inch flexible polyethylene line leading to the reservoir and main laboratory. To reduce pressure surge when the intake pump operates, an antisurge unit is built into the system at the junction of the three branches of this water line (fig. 1). To eliminate surge, a separate line is being laid from the intake pump to the reservoir.

A turbine-type pump of smaller capacity (80 gallons per minute) was formerly used. This type also provided pro-

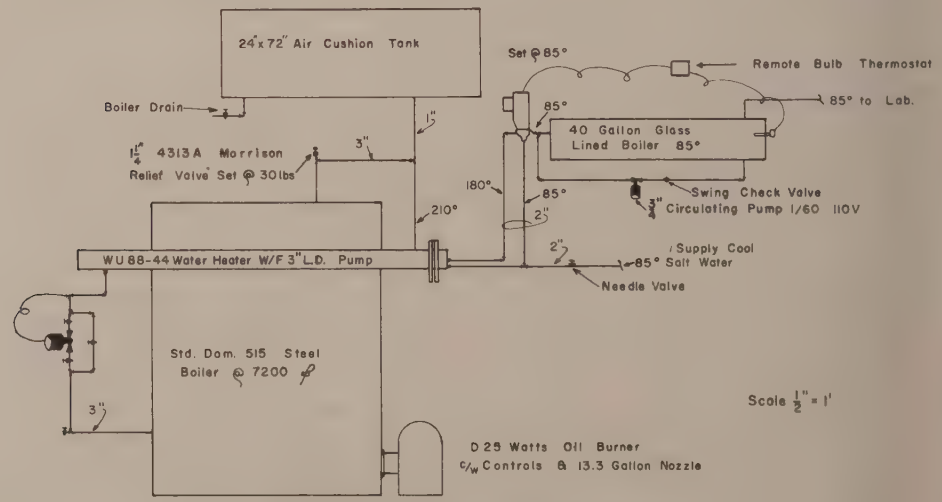

FIGURE 2.—Diagram of salt-water furnace.

tection from supersaturation with gases. Although it was generally satisfactory, the rigid intake pipe enclosing the propeller shaft must be protected from damage from such things as boats, drift ice, and other causes. For example, the shaft of the turbine pump was severely damaged when the former wharf settled suddenly. An enclosed pumphouse is also required.

To reduce the possibility of contamination from metal ions, the use of metal is avoided whenever possible (figs. 3 and 4).

Piping

Plastic piping of polyethylene and polyvinyl chloride (PVC) is used throughout the laboratory buildings. There has been no evidence to suggest that either material is toxic. The underground piping is flexible polyethylene and is laid below frost level. Rigid piping is used in the laboratories because fewer supports are required and the sidewalls of the pipes can be tapped to receive stopcocks where required.

FIGURE 3.—Hot and cold salt-water, fresh-water, and compressed-air piping along the west wall of the basement laboratory.

FIGURE 4.—Overhead salt-water and compressed-air lines in the basement laboratory.

Valves and connectors throughout the system are of nontoxic plastic materials, usually rigid PVC but in some cases a blend of styrene acrylonitrile-butadiene copolymer, sold under the trade name Uscolite.

The most satisfactory valve design used to date in our experience is a ball valve of rigid PVC using soft-seal seat rings of Teflon. This valve does not stick even after prolonged periods in either the open or closed position. Only a quarter turn is required to close the valve. No pressure is needed to effect a tight seal.

All piping is black or gray to exclude light and thereby inhibit seaweed growth. Differently colored pipes can be used as a key or code to the contents and supply points. Fouling by mussel growth and occasional clogging with silt and sand are continuing problems. To reduce clogging and to facilitate cleanout, straight runs of pipe are used wherever possible. Cleanouts (tees instead of 90-degree elbows) and break-away couplings are provided at the ends of straight runs of pipe. Although considerable cleanout is accomplished by flushing, it is sometimes necessary to clear sections of the pipes with mechanical reamers. Numerous shutoffs are located at strategic places to allow partial shutdown to repair, to clean out, or to extend the lines. Wherever possible, pipes and fittings are exposed and readily accessible.

Routine late-fall cleanout eliminates much of the yearly accumulation of mussels and silt.

Condensation on pipes conducting cool water throughout the laboratory is troublesome, particularly during hot humid weather. Aside from personal annoyance, drip from overhead pipes on electrical equipment is dangerous. Pipes distributed through laboratory areas should be insulated.

HEATING AND OTHER FACILITIES

The heater system consists of a standard heating boiler of the horizontal return tube type, fired by a thermostatically controlled oil burner. The fresh-water boiler output feeds into the shell of the heat exchange. Heat is transferred to salt water contained within stainless-steel (type 316) heat-exchange tubes. The salt water leaving the exchanger is heated to 180° F. This 180° F. salt water is in turn mixed with cool sea water by means of an automatic motorized 3-way valve to produce salt water at 85° F. for distribution to the laboratories. The system has the capacity to heat 20 gallons per minute of salt water from 32° F. to 85° F. (fig. 2). Required temperatures at the experimental tanks are controlled by blending hot (85° F. water) and cool sea water to achieve the desired temperatures.

Thermoregulators

Thermoregulators, relays, and small pumps for either hot or cool sea water are used on individual tanks to overcome temperature fluctuations resulting from slight changes in flow, changes in room temperature, and changes in temperature of the cool sea water. By this means, it is possible to control temperatures to within 0.2° F. in tanks of 100- to 200-gallon capacity without insulation. This system eliminates the use of dangerous electrical immersion heaters.

Aeration

Two interconnected 5-horsepower DeVilbiss air compressors supply compressed air for aeration of the water in individual tanks. Copper piping distributes the compressed air around the laboratories. To avoid carryover of any toxic metal ions, an expansion valve at the outlet of the compressor dries the air as it leaves the compressor. Additional drying tubes can be fitted to individual outlets when necessary. Compressed air is distributed in the experimental tanks with "air diffuser" or "air breaker stones."

Refrigeration

Special facilities to refrigerate salt water have not yet been acquired. Low temperatures are obtained naturally during the winter months. Some individual tanks are maintained in a controlled-temperature walk-in cold room. With no flow of water through tanks in the cold room, the water is aerated to maintain suitable oxygen content. A small portable refrigeration unit with a stainless-steel cooling coil is used to cool single experimental tanks.

Reduced salinity

When required, reduced salinities are obtained for individual experimental tanks by mixing suitable constant flows of salt and fresh water.

Filtration

When required, filters with disposable cellulose cartridges are used on the water supply to individual tanks.

SPECIAL PROBLEMS

Electrical-power or equipment failure has been anticipated at St. Andrews. Auxiliary generating equipment has not been installed to date but a gasoline-driven emergency pump and a standby electric pump are available. In addition, the reservoir has sufficient capacity to maintain flows of water to the experimental and

storage tanks for several hours. Provided there is no electrical failure, animals can be kept alive during breakdowns in the pumping system by aeration in individual tanks with compressed air. In an emergency, the salt-water fire-fighting unit can be used to maintain the required level of sea water in the reservoir.

Although two possible causes of supersaturation with gases are eliminated in our system by using a submersible pump and avoiding air-cushion pressure tanks, heated water from the furnace equipment may be supersaturated at times. To overcome this, equilibration columns are used for individual tanks or groups of tanks. Similar columns, using nitrogen from cylinders of compressed gas, are used to provide water with a low content of dissolved oxygen for special experiments.

ALARMS

At St. Andrews, an alarm system signals when water levels in the reservoir fall below a predetermined level indicating a pump or waterline failure. A second alarm system monitors water supply to experimental tanks. Alarms at the tanks can be at the discretion of the researcher. At St. Andrews, alarms are incorporated in an automatic, multipoint temperature-recording system.

SUMMARY

At the present stage of evolution of the salt-water system at the St. Andrews Station, certain difficulties have been overcome.

Submersible pumps eliminate air leaks at the suction end, a major cause of supersaturation with gases. Except for the aluminum and stainless steel in the pumps, all metals have been eliminated by use of plastic pipes and fittings.

The reservoir tank provides an almost constant pressure head and, in addition, a reserve supply for several hours in case of breakdown.

Thermostatically controlled heated sea water maintained by an oil-fired furnace eliminates practically all potentially dangerous electrical equipment in and around the experimental tanks.

Although compressed air for aeration is distributed in copper pipes, an expansion valve dries the air as it leaves the compressor to eliminate possible carryover of toxic metal ions.

Design of the system for easy cleanout helps to overcome difficulties arising from clogging with mussels and silt.

The system functions well at present, but is not trouble free. Continued improvement is required.

A separate feed line from the reservoir to the laboratories is planned to overcome present surge difficulties.

Greater duplication of the system is required, including greater attention to placement details for readily accessible shutoffs and convenient shunt lines.

Partial filtration of the system is required to combat occasional heavy silting caused by wave action on the beach or heavy rains. As an alternative, relocation of the intake into deeper offshore water where there may be less silt is being considered.

All the water from the tanks runs to waste. Although possibly desirable, the furnace heater is not equipped with a feedback system to conserve energy.

Refrigeration of part of the supply is desirable to extend the scope or flexibility of the maintained environmental conditions.

Insulation of pipes, fittings, and tanks would be an improvement for easier maintenance of required conditions, for conserving energy, and to increase the safety standards of the establishment.

Standby generating equipment is required to maintain basic facilities during periods of power failure.

SEA-WATER SYSTEMS AT THE FRIDAY HARBOR LABORATORIES OF THE UNIVERSITY OF WASHINGTON

By Robert L. Fernald, *Director*

Friday Harbor Laboratories, University of Washington, San Juan Island, Wash.

Abstract.—The Friday Harbor Laboratories are on San Juan Island, Wash., in an area where the sea water is relatively free from industrial pollution and fresh-water runoff. Three separate sea-water systems are in operation. Two have glass piping over the span of 1,500 feet from pumps to laboratories; the third has polyethylene piping. Each has a hard-rubber centrifugal pump; a 250-gallon, glass-lined receiving tank maintains a constant head of pressure in the laboratories. The water enters the laboratories with little or no change in temperature, or fauna.

The field laboratories for marine sciences at the University of Washington, the Friday Harbor Laboratories, are located on some 484 acres of shore property on San Juan Island, Wash., approximately 80 miles to the north of Seattle. The Laboratories were established in this general area in 1904, and development on the present site began in 1924. In recent years, the past 12, we have had some experience in the design, construction, and operation of sea-water systems which may prove of interest to similar laboratory operations.

At present we have in operation three more-or-less separate and independent sea-water systems. However, two were designed in such fashion that the lines may be interconnected and the water mixed in delivery to the several smaller laboratory buildings. The three systems have a number of features in common. All draw water from a single location marked by the "cantilever pier" shown in figure 1, on a point at the entrance to Friday Harbor proper and projecting into San Juan Channel along the east side of San Juan Island. The sea water at this site is highly stable in temperature, is well mixed, and is free of pollution and fresh-water runoff. The intakes are in the rapidly moving current of sea water just below extreme low water level. It is anticipated that in the near future the intakes will be lowered an additional 5 feet to reduce clogging by free-floating *Ulva* and other algae in late summer. Each intake by way of a 3-inch hard-rubber foot valve is protected by a screen of polyethylene.

In addition the water in each system is pumped by a hard-rubber-lined centrifugal pump powered by an electric motor. Both 5-hp. and 7½-hp. motors are in use and are operated continuously when the system is functioning. The suction lift is approximately 15 feet at low water. In each system the water is carried some 1,500 feet to the laboratory area where it is delivered to a 200-gallon glass-lined tank outside the laboratories. The three receiving tanks are of the same small size to avoid holding the water for any appreciable period of time and thus risk marked change in temperature of the water on unusually cold or hot days. Each receiving

FIGURE 1.—Cantilever pier and pumphouse.

tank is approximately 15 feet above the level of delivery to the sea-water tables and tanks in the laboratories; the tank thus acts as a basis for a controlled gravity-feed system to the tables and aquariums. One of these receiving tanks manufactured by the Pfaudler Company is shown in figure 2.

The lines to the laboratories and the distribution system within the laboratories are of Pyrex glass pipe with standard rubber gaskets and aluminum flanges. The outlets to the individual sea-water tables and aquariums are devised from regular 4- and 6-mm. laboratory stopcocks. The assembly for the stopcocks is illustrated in figure 3. These have proven to be highly satisfactory and far less expensive than other commercially available glass spigots.

The systems differ in the type of piping used to conduct the water from the pumping station to the receiving tanks. The oldest system, installed in 1950, and the newest, installed in 1962, are of Pyrex glass pipe, 2 and 3 inches in diameter respectively. Each of these lines is insulated against temperature variation by enclosure in a sheeting of aluminum over a ½-inch thickness of glass wool in the 2-inch line and foam rubber of similar thickness in the 3-inch line. This insulation insures delivery to the sea-water table of sea water of a temperature essentially characteristic of that in the channel from which it was taken. On the hottest days of the summer, when the temperature is approximately 90° F., the change in temperature of the sea water is less than 0.5°

FIGURE 2.—Receiving tank.

C. as it travels to the laboratory. The insulation for the 2-inch line is shown in figure 4. The remaining system was installed in 1959 of 3-inch polyethylene piping. This is virgin grade with a pressure test of 75 pounds per square inch and approved as completely nontoxic by the National Sanitation Foundation. This line was not insulated but has been painted with aluminum paint. Temperature change in the water along this line in hot weather may be as much as 2° C.

Our aquariums and water tables in the laboratories are of two types. In the older systems they have been constructed from 2-inch Douglas-fir, assembled in such fashion that no metal of nails or screws is in contact with the sea water. The wood is untreated and becomes infested with *Bankia* and *Limnoria* each season, but these have been controlled by rotation of use or intermittent use so that only a few of the tables and aquariums have required replacement in the period of almost 12 years. The aquariums are of simple design; in most cases they are approximately 50 by 24 by 12 inches and the sea-water tables are approximately 50 by 42 by 4 inches. They are supported on frames constructed from 1½-inch iron pipe,

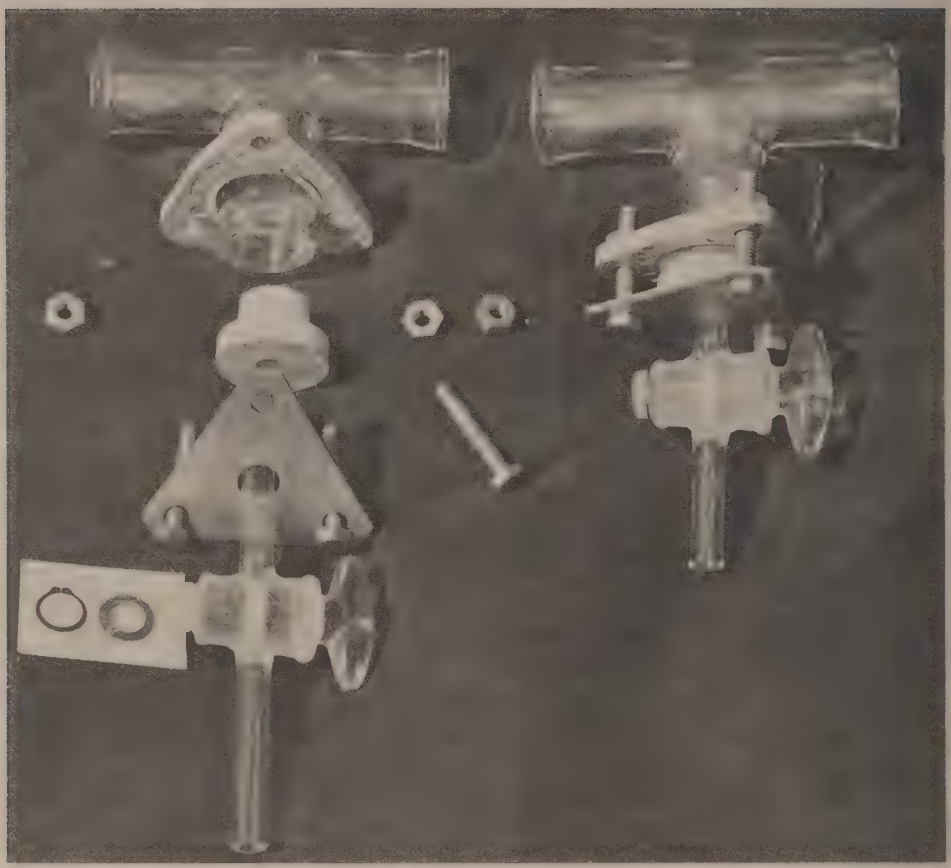

FIGURE 3.—Pyrex stopcock.

welded in the appropriate design and painted with rustproof paint (see fig. 5).

In the research laboratory recently completed, the aquariums and sea-water tables have 3/8-inch plexiglass sides and bottoms. The tanks are supported on the pipe frames on sheets of 3/4-inch marine plywood to avoid putting stress on the plexiglass. In addition, the new research building is equipped with a few reinforced-concrete tanks of different sizes and shapes. Among the more useful are two circular tanks 8 feet in diameter and 30 inches deep. These are especially well adapted for the maintenance of more rapidly moving and swimming animals such as squid and fish. Another concrete tank is a large rectangle, 5 by 10 feet, varying in depth from 1 to 3 feet. Other concrete tanks are developed as double-deck water tables, 3 feet wide, 8 inches deep, and as long as 14 feet, with 17 inches' clearance between the two tanks.

In carefully conducted tests to determine the suitability of a wide variety of plastics and substitute piping materials for use in sea-water systems, we found nothing more satisfactory than Pyrex glass. Many materials proved quite unsatisfactory and some essentially useless.

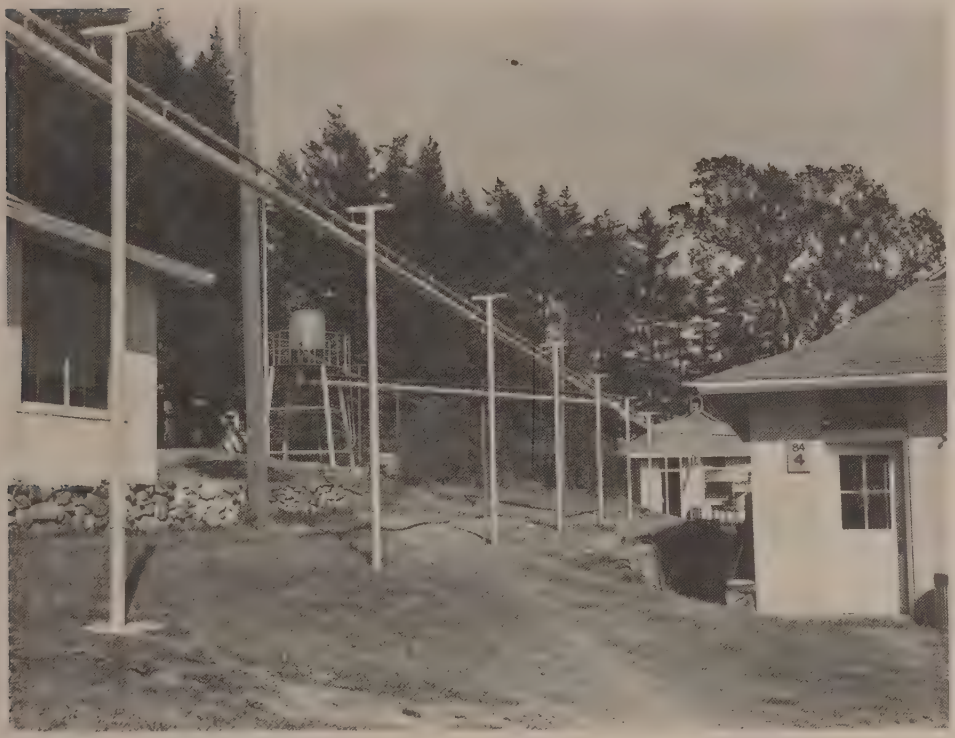

FIGURE 4.—Insulated glass line from cantilever pier to receiving tanks.

Polyethylene of virgin grade and highest quality, while sometimes varying from one production lot to another, proved superior to other commonly recommended plastics. While many of these plastics are advertised as "nontoxic to humans" and appear to have no obviously deleterious effect on many adult marine invertebrates, they may block developmental stages or cause serious abnormalities of differentiation.

Developing eggs and embryos of the purple sea urchin, *Stronglyocentrotus purpuratus*, have been used to real advantage as test subjects to determine the toxicity of various possible materials for use in sea-water systems. Since they have been used extensively as experimental material in this laboratory, their development is very well known and any variation from the normal in rate or kind of development can be readily detected. In addition they are quite sensitive to heavy metals and other toxic agents and the presence of minute quantities of such is usually reflected in dramatic change in the normal pattern of development.

As will have been noted, there is no filtering of the sea water pumped through our systems. The water arrives at the tanks with the usual complement of planktonic organisms, and plankton feeders thrive in the tanks and aquariums. In addition, since the system is essentially free from toxic agents, the walls of the pipes provide settling space for larvae of many sessile forms and other animals taken in at the intake. Thus the system supports a considerable growth of barnacles, mussels, limpets, etc., as operation continues.

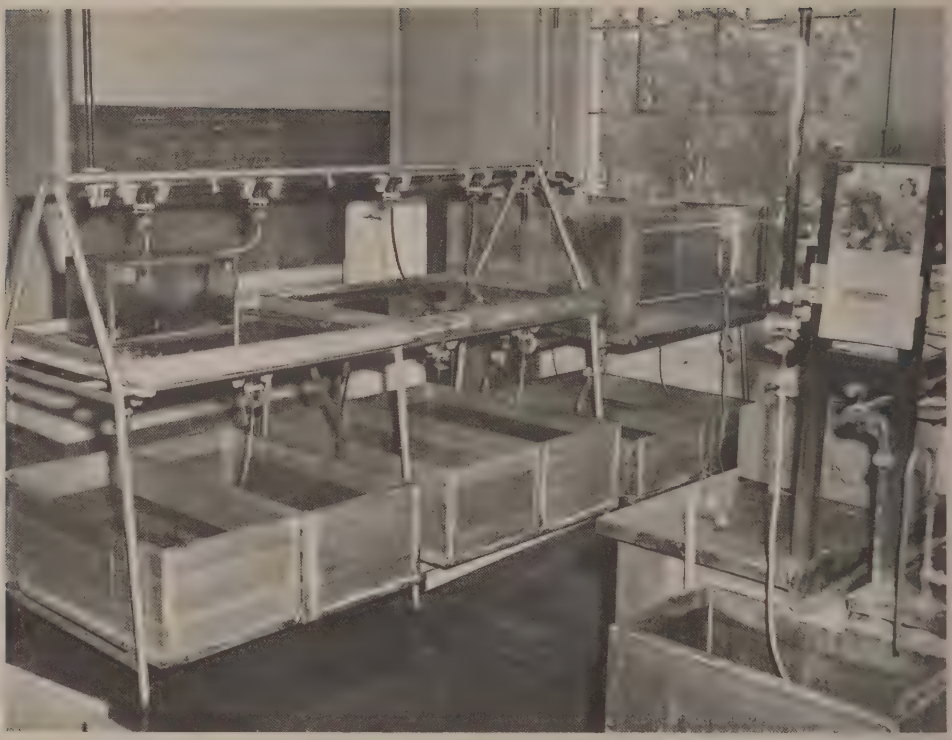

FIGURE 5.—Distribution system, water tables, and aquariums.

Experience has indicated that the best method of removal of excessive growth is by mechanical cleaning of the lines. Fresh water, hot or cold, and acids have proved to be too slow and inefficient to eliminate this growth, and a simple dismantling of certain of the joints followed by pulling of various-sized rubber stoppers through the line has proved more satisfactory and constitutes a less-time-consuming interruption to service. Such a cleaning is required annually throughout the system and more frequently in certain sections. Excessive growth of diatoms within the glass lines has been controlled with some success by covering the lines with sheets of aluminum foil.

In evaluating the systems which we now have in operation at the Friday Harbor Laboratories, there is no question but that the combination of a pump lined with hard rubber, a well-insulated line of Pyrex glass pipe coupled by rubber gaskets, a receiving tank with glass lining, and sea-water tables and aquariums of wood or plexiglass give assurance that the system will deliver water with physical characteristics as nearly like those of the water at the source where the intake operates and as free from contamination with heavy metals as can be desired. In a laboratory such as ours, where the demands for sea water are such that not only must a copious supply be maintained but also it must be nearly the temperature of the channel water and as free from contamination or toxic agents as possible to assure optimal culture conditions for everything from embryos of invertebrates to various algae and fish, the glass systems which we have are excellent.

OREGON FISH COMMISSION'S SALT-WATER SYSTEM AT NEWPORT, OREGON

By C. Dale Snow

Research Laboratory, Oregon Fish Commission, Newport, Oreg.

Abstract.—This paper describes a simple salt-water system used at the Oregon Fish Commission's shellfish-research laboratory at Newport, Oreg., and discusses some of the problems in maintaining and operating such systems.

Our salt-water system at Newport, Oreg., is simple and is illustrated in figure 1. Water is pumped into a 750-gallon Douglas-fir tank that has been treated with biturine to slow down damage by *Teredos* and *Limnoria*. The pump in use is a 1-inch Jabsco powered by a ½-horsepower electric motor, but a Gould pump with glass liner and impeller would be far superior. Pumping is regulated by an Allen-Bradley float switch that can be operated automatically or manually. Placement of the outlet from the tank 6 inches above the bottom reduces the amount of sediment pumped into the aquarium trays. For piping water from the tank to the aquarium we use 1-inch Portco plastic pipe. Aquarium trays are made of ½-inch marine plywood that is also treated with biturine. The water supply into the aquarium enters through one to four tee-joints placed in the salt-water line. Each tee has a rubber stopper with a ¼-inch glass tube through the center and a piece of surgical tubing on the end to which a screw clamp is attached. The amount of water entering is regulated by this clamp and the free fall into the aquarium aids in aeration. A 1-inch hole with a rubber stopper and a ½-inch glass-tube standpipe regulates depth of water. To clean the trays, the stopper is removed and the trays are scrubbed with a heavy brush as the water drains out. This system, while quite simple, has proven to be adequate for our purpose of holding animals (clams, crabs, etc.) for various studies.

The biggest problem with this system has been fouling of the water lines by mussels and barnacles. To combat this we periodically flush the lines with hot water during the spring and summer months to control settling and survival of these animals. If the lines are neglected and growth becomes too heavy then the lines must be disassembled and a half-strength Clorox solution run through the pipe. This solution dissolves the byssal threads of the mussels and allows the mussels to be flushed out. If Clorox is used, the lines must then be thoroughly flushed before they are used again. I would recommend that salt-water lines be put together in such a manner and position that they can be taken apart easily for periodic cleaning.

In our salt-water system the outlet placed well above the bottom has proven adequate in allowing sediments to drop out and it holds to a minimum the sediments entering the aquarium. Periodically we allow the level to drop down so that the bottom sediments can be removed with a garden hose siphon. A recent innovation

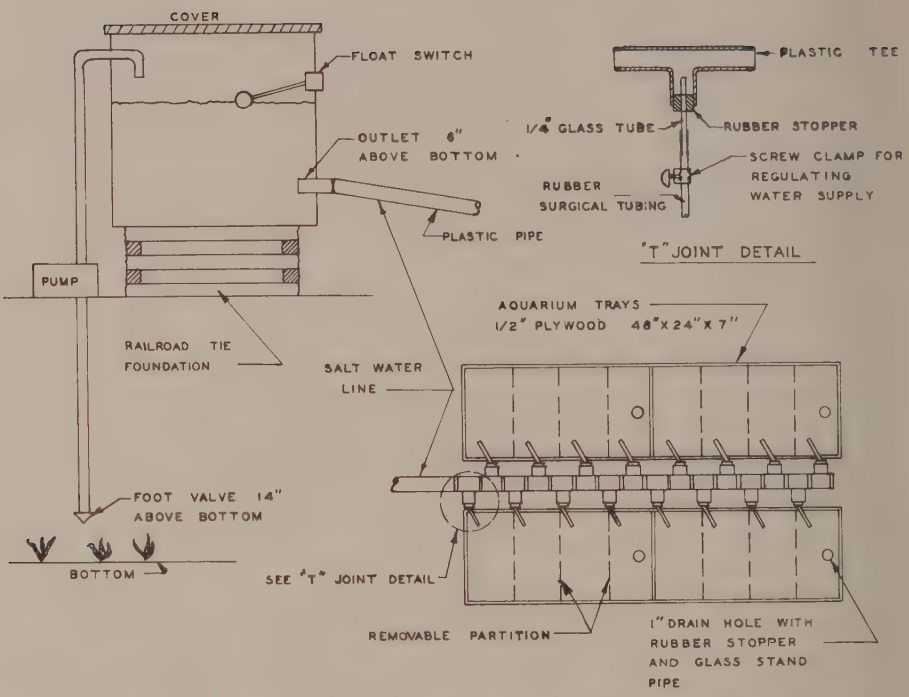

FIGURE 1.—Marine aquarium of the Oregon Fish Commission, Newport, Oreg.

in some water tanks is the lining of the tank with a polyethylene sheet. This not only discourages *Teredos* and *Limnoria* but facilitates cleaning of the tank. Cleaning merely involves removal of the polyethylene which can be hosed off. Unfortunately, with the polyethylene liner you must depend upon siphoning action for your water supply.

Equipment failure has been a minor problem in our system. This is particularly true where the storage tank's capacity is such that it will supply water for several hours. We try to keep a spare motor and impeller for the pump on hand at all times, as these are the two items most likely to cause trouble.

The selection of a pump for a salt-water system depends much on the use to which the water will be put. In our work the 1-inch Jabsco pump has proven highly satisfactory, but for some work this would be inadequate, particularly in oyster or larvae work. The brass liner in this pump can cause trouble. For larval rearing or oyster studies a pump with a glass liner and impeller is far better.

Toxicity of components within the salt-water system is highly important when you are working with larval forms or condition studies. This toxicity can come from a number of sources: (1) The liner or impeller of the pump; (2) materials used to treat the tanks and aquarium trays; and (3) some plastics used for pipes or tank liners. In general it is best to avoid all metals within the system. Plastics such as Portco piping, polyethylene, and some of the new marine resins are nontoxic to most invertebrate larvae and have proven satisfactory in most instances. Cements with high lime contents should be avoided unless the material has been cured for several years in salt water.

I prefer storage tanks as a source of water supply. A tank has several advantages over a continuous-flow pump: (1) better salinity control, (2) water reserve in case of pump failure, and (3) sediment control. In an estuarine situation a continuous-flow pump picks up water at all tide and salinity phases. With a tank you can pump during the high water when salinity is greatest, thus holding salinity at a level you desire. However, wood tanks, if not lined with polyethylene or treated, will be destroyed by marine boring organisms such as *Teredos* or *Limnoria*.

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AN ANNULAR TANK FOR SEA FISHES

By Allan C. DeLacy, *Professor of Fisheries*
University of Washington, Seattle, Wash.

Abstract.—The College of Fisheries of the University of Washington maintains an 8,000-gallon recirculating sea-water system. A 2,000-gallon annular tank has enhanced growth and longevity of certain fish species. Light and temperature control afford flexibility in establishing artificial environments.

The College of Fisheries at the University of Washington maintains a recirculating salt-water system with a total capacity of about 8,000 gallons. Rubber-lined steel pipes, sumps, and storage tanks are prominent features of the system. Twelve rectangular aquariums of concrete and glass, a 2,000-gallon annular tank of rubber-lined steel, and a single 450-gallon fiberglass-lined wooden tank comprise the permanent fish-holding facilities. Additional important features of the system are the sand filters, temperature-control equipment, and flexibility which permits the entire system to be operated as a unit or allows subdivision into two independent systems, one for cooling and one for warming sea-water as desired. Temperatures commonly fluctuate less than 1° F. from a chosen level.

The annular tank (fig. 1) has proved to be a feature of particular interest in the College of Fisheries salt-water system. It is simply a 3-foot-wide annular channel with an outer diameter of 10 feet. A water depth of 4 feet is maintained. Two inlets discharge into the surface at a slight angle thereby producing a weak circular current in the tank. Four evenly spaced surface openings on the inner wall serve as outlets. A bottom outlet is used when the water level is to be lowered. Eight 16-inch-square glass ports in the outer wall and four in the inner wall permit lateral viewing and photography of contained specimens.

Active fish cruise around and around in the annular tank making infrequent contact with the sides. A fingerling silver salmon (*Oncorhynchus kisutch*) was reared to maturity (5 pounds) in the tank without experiencing the deformities and damage to the snout which accompany confinement in the smaller (200-gallon) rectangular aquariums. Two ratfish (*Hydrolagus colliei*) lived 3 years in the tank and finally died after an operational error which permitted a temporary but severe temperature increase. A skilfish (*Erilepis zonifer*) introduced to the tank as a 3-pound, 17-inch fish weighed 36 pounds and measured 39 inches in total length after 6 years.

Total water use by all aquariums averages about 20 gallons a minute. Over a period of several months, salinity may fluctuate through a range of 1 part per thousand, and pH may decrease by a half a unit. Frequency of water replacement is related to type and number of organisms being held but in general from one-half to three-quarters of the water in the system is replaced three or four times a year. New water is brought to the campus by wooden barge from nearby Puget Sound.

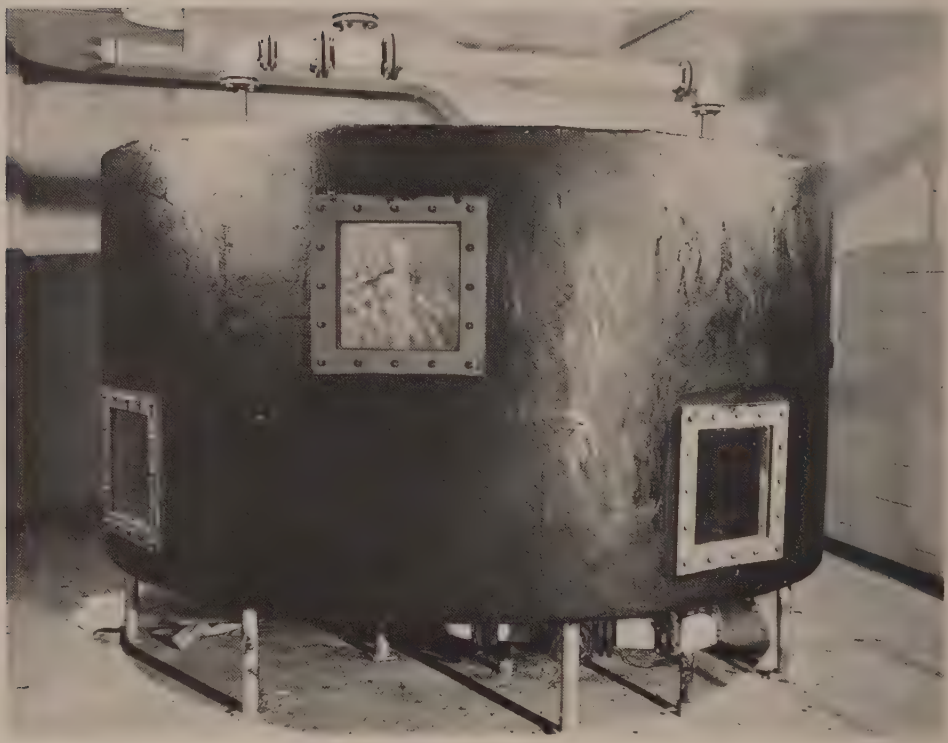

FIGURE 1.—Annular tank at the aquarium of the College of Fisheries, University of Washington, Seattle, Wash.

The sand filters have given satisfactory service since the initial operation of the aquarium system. A gradual decrease in filtration rate usually occurs over a period of several weeks. Occasional stirring of the sand accelerates filtration, but full efficiency is regained only by backwashing the filters. Fresh water is used for backwashing.

An addition to the salt-water system as originally constituted is a fiberglass-lined wooden tank 39 inches wide by 24 inches deep by 10 feet long. The fiberglass lining of the tank proved to be satisfactory and remains in good condition after 42 months of continuous service.

A problem involving fish behavior arose in connection with lighting. All aquariums are in an interior room with no exposure to daylight. Sudden illumination of the room caused some species to dart wildly about, striking sides or bottom of aquariums or sometimes leaping out of the tanks. An effective solution was developed by installation of an auxiliary room light controlled by a time clock which activates a motor-driven rheostat. The light comes on or goes off over a half-hour period, and the duration of "night" and "day" can be adjusted as desired. In practice the time clock is reset several times a year to simulate the lengthening and shortening of days by season.

SEA-WATER SYSTEM OF THE MARINE LABORATORY OF THE UNIVERSITY OF CALIFORNIA, SANTA BARBARA

By Donald K. Joice, Office of Architects and Engineers,
and Demorest Davenport, Department of Biological Sciences,
University of California, Santa Barbara, Calif.

Abstract.—The sea-water intake system of the Marine Laboratory of the University of California, Santa Barbara, lies in the tidal zone of the campus beach. The 48-square-foot filter, a concrete box filled with graded aggregates and having a perforated collection header at the bottom, is located at low-tide level. The filtered water is carried to the laboratory through a buried pipe under the suction of a shore-based jet pump. As a cleaning device, the surf's constant agitation of the beach sand over the filter has contributed to giving an uninterrupted, maintenance-free service of 35 gallons per minute for over 4 years.

The sea-water system of the Marine Laboratory on the campus of the University of California, Santa Barbara, is made up of three basic components: a sand filter intake unit located in the surf approximately 400 feet from the shoreline, a jet-type pump assembly, and a reservoir head tank combination located on shore near the laboratory.

The filter unit has been in operation almost continuously for 4 years without any malfunction, or any maintenance. The pumping portion of the system has required only the type of maintenance and replacement program normal to any pumping plant.

This paper will deal primarily with the sea-water intake unit, which is the critical component of the system. Figure 1 shows the relations of the three components.

The physical characteristics of the campus beach placed certain limitations on the installation. The beach floor is of an impermeable but relatively soft monolithic shale which is known to be over a thousand feet deep. This shale, with a surface elevation of 1.5 feet at the shoreline, tapers off slightly over a foot in 400 feet. From this point it slopes off at a more acute angle, dropping approximately 3 feet in the next 100 feet. In certain winter months the wind and tides clear virtually all sand from the shale leaving it as barren as a table. At such periods the surf comes within a few feet of the shoreline. During the summer months tidal action redeposits the sand on the beach to a depth of from 2 to 6 feet. During these periods the surf will be held out as much as 400 feet from the shoreline.

The intake filter unit is a flat reinforced-concrete box (fig. 1), with 6-inch walls and bottom, 6 feet by 8 feet by 2½ feet inside dimensions. A header made up of 4-inch cast-iron bell-and-spigot crosses runs the length of the box at the bottom. Ten cast-iron perforated laterals, 2 inches in diameter, are lead-caulked into the header. The box is filled with graded aggregate to form the filter, the purpose of which is to screen out sand and flotsam.

The filter unit is buried in the floor of the beach, the top being approximately level with the shale floor at elevation −1.5. The

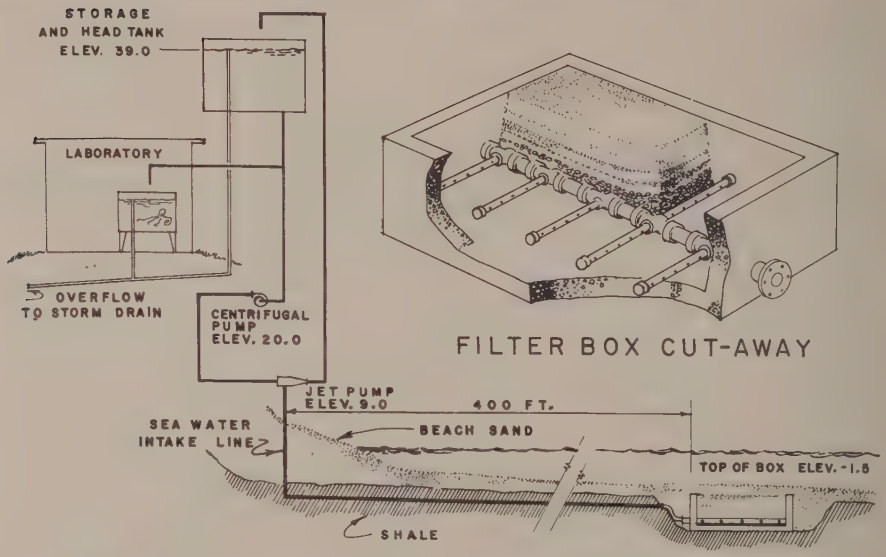

FIGURE 1.—Piping diagram and cut-away view of filter box in sea-water system of the Marine Laboratory of the University of California, Santa Barbara, Calif.

beach sand covering, ranging in depth from 18 inches to approximately 48 inches, depending on the season, augments the integral filter media of the unit. The area over the filter is covered with water for all but a few of the lowest tides of the year. The unit is connected to the shore installations by a 4-inch asbestos-cement pipe suction line which is also buried and concreted in the beach floor shale, to protect it against tidal action.

The size of the filter unit was determined by a number of factors, all of which were strongly influenced by economic considerations. The prefabricated unit, with 48 square feet of filter area, was designed to provide the 30 gallons per minute required for a small marine laboratory. Weighing approximately 10 tons, it was of a size and shape that could be readily hoisted on and off a truck or trailer.

The total beach installation was completed in 1 day between a high and low tide. As the high tide began to recede, bulldozers followed it out, clearing the 3 feet of sand from the strip which was to be trenched for the pipe installation. As the bulldozers left the shore they were followed by the survey crew, who set grade stakes and were in turn followed by the trenching machine. The pipe-laying crew, assisted by portable pumps to remove seepage from the trench, came only a few yards behind. As soon as four or five lengths of pipe had been installed and fixed in place, transit-mix cement trucks poured concrete over the line. In preparation the bulldozers pushed the sand into revetments along the course of the project. These revetments, which averaged about 8 feet high, enclosed the total work site on the ocean side and served as a cofferdam to hold back the incoming tide late in the afternoon. This gave the construction crew an additional 4 hours of time which the tides would not have otherwise permitted.

A depression approximately 36 inches deep was bulldozed out for the filter location, and the filter was lowered into place. It was then fitted with a reinforced-rubber suction hose, the flexibility of which al-

lowed the final connection to the rigid asbestos-cement pipe line. Bolted flanges were used on these field connections to further speed the installation.

Whereas this filtering system borrowed some of the characteristics of the rapid sand filter used for industrial and municipal water handling, the controlled conditions under which a rapid sand filter is backwashed and maintained were considered impossible to attain in a varying tidal zone situation. It was therefore determined to establish a rate of flow which would be so slow that the dirt absorption in the filter would be negligible. By utilizing this reduced flow it was assumed that air bubbles which result from the negative pressures developed in high-rate filters would not collect to halt the flow. In a small test filter model 1 foot thick it was observed that the rate of water flow through local beach sand was slightly over 1 gallon per minute per square foot under a head of 1 foot. Knowing that there would be tidal heads of up to 8 feet over the filter, which would increase its efficiency, a design rate of 0.65 gallon of water per square foot per minute appeared safe. This rate has been maintained for 4 years of operation with no evidence of a decrease.

The only apparent explanation for the lack of servicing demanded by this system is its location in the surf. It is situated at a point where there is nearly always a strong tidal action and constant movement of sand over it. This sand movement, it is believed, has served as an automatic filter-cleaning device. The first 18 inches of beach sand immediately covering the unit is thought to remain relatively undisturbed except for heavy storms of a severity which is expected only once in several years. The sand above this point is known to be constantly shifting under the normal movement of the surf.

Although it was assumed during the system's design that the shifting of the beach sand would help maintain the filtering qualities of the unit, it was also presumed that the periodic replacement of the surface material would be relatively inexpensive if trouble developed. A south-coast oil refinery sea-water intake system which utilized a beach-sand filter operated successfully for about 2 years before becoming sealed up by accumulation of organisms in the sand above it. This unit, which was nonportable, was located near the shoreline where there was only an occasional tidal flow over it. It depended largely on lateral infiltration through the sand. It was reported to have been maintained in operation after the first stoppage by a periodic chlorine sprinkling treatment of the sand over the filter. In anticipation of such a development the UCSB installation was provided with a connection to the campus domestic water system. It was assumed that a fresh-water back-rinse would help control such growths. None have been detected to date, and the sea water in the laboratory is to all intents and purposes plankton free.

The choice of a pumping system as in the case of the filters was determined in part by the limited finances available. The most economical installation on a first-cost basis was considered to be a jet-pump installation. This system consists of a high-head centrifugal pump energizing a venturi which creates the negative head to draw up the ocean water. The centrifugal pump operates in a loop arrangement. It draws its water from the head tank, discharges it through the venturi back into the head tank. For each gallon of water pumped through the venturi approximately 1 gallon of fresh sea water is drawn in from the ocean and discharged into the head tank. The head tank holds 2,000 gallons of sea water which will normally supply the laboratory and the re-

circulating centrifugal pump for several hours even though the sea-water intake is temporarily interrupted by a low tide. As the rising tide covers the filter unit the suction from the venturi automatically re-establishes the sea-water flow. The centrifugal pump is protected from running dry by a float switch in the head tank which breaks the circuit in the event the tank water level drops too low.

The economy of the jet system stems from its versatility of location. It can be located considerably above the source water level and still afford a reliable automatic priming function. To have installed a centrifugal turbine pump, which, budget permitting, would have been seriously considered, the pump would have had to be located at elevation 1.5, the terminal level of the pipe from the filter unit. Priming could have been assured only by having the pump at this elevation, which is below the level of the ocean. The higher comparative cost of this installation would have developed from the pump house itself. Instead of being located in a frame structure on the shore at elevation 9.0 as was the jet-pump installation, the turbine pump would have required a reinforced-concrete vault with foundations at elevation −4.5.

Although the simplicity of the jet-pump automatic priming and control system presents great advantages, in view of the demands made upon it by the specific environmental conditions, the relative inefficiency of its operation as compared to a turbine pump should be considered. For example, in the system exhibited in figure 1, a 10-horsepower motor for the jet-pump system is required to deliver 30 gallons per minute of ocean water, whereas a 1-horsepower motor would accomplish the same work with a direct turbine pumping unit. This ratio of 10 to 1, if reflected in electrical energy costs, becomes highly significant in equipment that operates continuously.

The above described system at present serves a small temporary laboratory containing approximately twenty 10-gallon and eight 25-gallon aquariums. There are three large table aquariums receiving running sea water in an outdoor installation.

Building schedules call for a tenfold expansion of present facilities in a permanent building, partially funded by the National Science Foundation, by June of 1964. All laboratories will be provided with running sea water. The sea-water system of this new permanent plant will be a modification of the present installation, employing multiple units of the same filter box.

SEA-WATER SYSTEM AT THE POINT WHITNEY SHELLFISH LABORATORY

By C. E. Lindsay

State of Washington Department of Fisheries, Brinnon, Wash.

Abstract.—A description of the original sea-water system of the Point Whitney Shellfish Research Laboratory of the Washington State Department of Fisheries includes local hydrographic conditions, piping, storage, pumps, distribution facilities, automatic controls, and provisions for cleaning. Considerations of cost, toxicity, materials available, and dependability determined the design. Although many of the operational problems inherent in this type of installation were solved initially, additional ones came to light with operation of the system. Some of these were subsequently eliminated by modification of various components, and others simply borne as limitations of the system. Later additions to the storage facilities and piping utilized new nontoxic plastics to expand capacity and versatility and eliminate damage from boring and fouling organisms. The effect of green concrete on quality of water was recognized. Recommendations for improvements to the present system and for development of a new system are made.

The Point Whitney Shellfish Laboratory of the State of Washington Department of Fisheries is on the west shore of Dabob Bay in Hood Canal, about 60 miles by road from Seattle. At this point Dabob Bay is approximately 1½ miles wide, has a narrow intertidal zone, and is 600 feet deep in the middle. Extreme tidal range is 17 feet. Surface temperatures range from 6° C. in winter to 21° C. in summer, and salinity ranges from 30 parts per thousand in winter to 24 parts per thousand in summer. Details of the hydrography of Dabob Bay are described by Westley (1956). Construction of the laboratory was completed in 1953, using an initial appropriation of $89,000. The sea-water system was incorporated into the building for use in conducting physiological experiments and bioassays and for live holding of oysters, clams, crabs, shrimps and other marine invertebrate animals. The system was relatively small, since the required uses did not include public aquarium displays or vertebrate fish holding facilities.

CONSTRUCTION AND OPERATION

Construction and operation of a sea-water system suitable for invertebrate animals has required the solution of many problems. The resultant system was a compromise between cost, toxicity, materials available, and dependability. The design was based on recommendations by fishery researchers on both the Atlantic and the Pacific coasts and our own previous experience with a smaller system at the Gig Harbor Laboratory.

Funds were insufficient to permit construction of duplicate continuous-pumping sea-water systems. Therefore a single-line system having foot valve, 4-inch main lines, main pump, standby pump, and 10,000-gallon wood storage tank was designed. Solutions to most of the problems peculiar to sea-water systems for invertebrates have been achieved

through initial design and construction features, and by subsequent modifications to correct deficiencies and extend the system for additional uses. The problems and solutions we used are briefly described in the remainder of this report.

Toxicity of the system was reduced as much as possible by the use of Johns-Manville Transite pipe for those portions of the lines which were outside the laboratory building, extending from the lower end of the suction line into the building and from the building to the sea-water storage tank. Inside the building, main lines were of 4-inch threaded hard rubber with 2-inch hard-rubber distribution lines carrying sea water to the aquarium area, and half-inch hard-rubber lines to individual laboratory sinks. Originally the only metal in contact with sea water consisted of a cast-iron foot valve, three cast-iron elbows, a 60- by 32-inch steel plate covering the top of the suction screen box, six cast-iron flanges, and four threaded steel pipe adapters used to connect the pump to the suction box and main discharge lines. Several types of protective coatings have been used on metal parts exposed to sea water. In order of use they were: Nitrose, Atco carbon elastic black, Gaco, epoxy resin, and powdered polyethylene. None of these has provided complete protection, but in general epoxy resin and powdered polyethylene appear most satisfactory. A major source of metal contact was the steel suction-box cover, which was finally protected with a ½-inch-thick neoprene blanket used as a gasket between cover and sea water in the box. In time most of the cast-iron and steel flanges and adapters were replaced with threaded Uscolite pipe.

The main pump from the beginning was an Ace Hard Rubber Company 2½-inch WEFM pump driven by a 7½-horsepower single-phase electric motor. The standby pump was a 1-inch 1-horsepower Gardner-Denver cast-iron centrifugal pump. Because of cost as well as anticipated corrosion difficulties, valves were kept to a minimum. Originally only two 4-inch rubber-lined diaphragm valves were incorporated in the discharge lines, positioned so as to permit direct pumping without use of the storage tank, or to permit use of storage-tank water only and allow dewatering of intake, suction screen box, pump, and initial section of the main discharge line.

Protection of the pump from physical damage or clogging is a vital consideration. Damage from ice formation was prevented by burying intake pipes underground and incorporating the pump room inside the main laboratory building. Exclusion of bottom detritus or substrate material such as gravel has been achieved by plugging the end of a 13-foot length of Transite pipe and perforating this pipe with ¼-inch holes spaced on ¾-inch centers over the full length of the pipe. Except for occasional growth of seaweed or accumulation of heavy barnacle or mussel set on the interior of the pipe, this type of screened intake has been entirely adequate.

However, when using hard rubber as a pump liner, it is also essential to eliminate the abrasive damage caused by shells of barnacles, mussels, or oysters which have set on the interior of the pipe and may later become detached and sucked into the pump. To avoid this difficulty, a suction screen box was cast as an integral part of the building inside the pumproom, and adjacent to the seaward wall of the building. In plan view, the shape of the box is a trapezoid whose bases are 54 inches and 28 inches; altitude is 38 inches, and depth 36 inches. It has a volume of approximately 32 cubic feet. Two screen slots were cast into the concrete. The 4-inch suction line was cast into the box on the short base of the trapezoid, and two pump suction flanges provided on the long

base. A 12 by 12 mesh per inch Saran plastic screen on wood frame was kept in one of the slots at all times and the top of the box sealed by a ½-inch steel plate and neoprene gasket, bolted down with 24 ¾-inch bolts set in a steel frame cast in the concrete (fig. 1). Elimination of most of the metal contact with sea water was

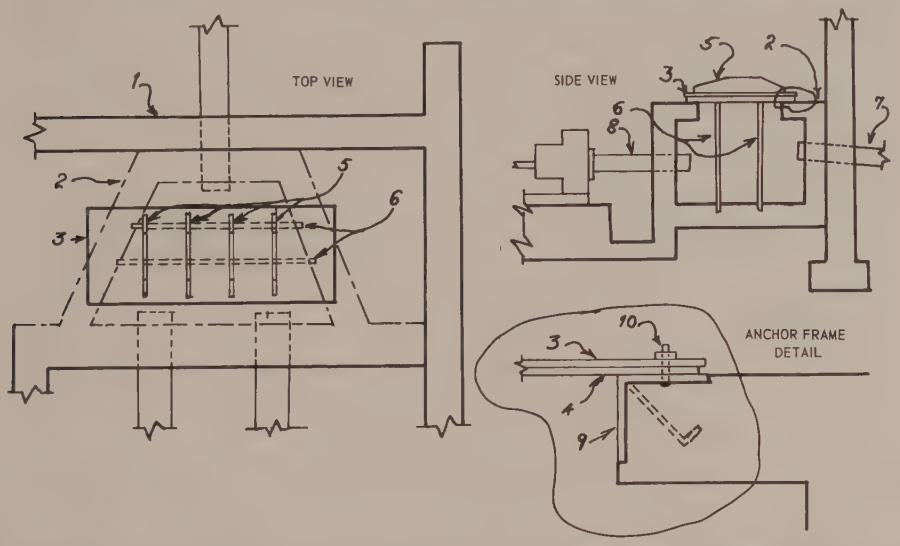

FIGURE 1.—Construction detail of the suction screen box at Point Whitney Shellfish Laboratory of the Washington State Department of Fisheries: *1*, building wall; *2*, suction-box wall; *3*, steel cover plate; *4*, gasket blanket; *5*, strong back; *6*, screens; *7*, 4-inch sea-water-intake line; *8*, 4-inch pump suction line; *9*, 4- by 4- by ⅜-inch angle iron; *10*, studpost.

finally achieved by placing a ½-inch-thick neoprene blanket between steel plate and suction box top. Holes for probe switch rod, primer pipe, and air cushion chamber were closed by threaded washers attached to black iron pipe nipples. In practice this device has proven somewhat troublesome to maintain, but has been valuable in providing combination screen and settling basin to minimize the amount of sand or other hard objects passing through the hard-rubber-lined pump. Certain design modifications of this type of suction box would eliminate features we have found unsatisfactory and still retain the basic advantages of the device.

The most important modification would be to change the relative position of box inlet and outlets so that pump suction is at least 12 inches below the bottom of the incoming sea-water suction line. At the same time the volume of water retained in the box above the pump suction should be nearly equal to the volume of the sea-water suction line lying above the level of half tide.

A source of difficulty has been maintenance of adequate vacuum while the system is on automatic operation, since porous spots in the concrete and poor bonding between anchoring ring and concrete sometimes allowed air to leak into the box. Box walls, therefore, must be of high and uniform density and should be concrete at least 10 inches thick. To reduce the area that must be fitted with removable gasket, the cover-plate opening should be made only large enough to allow insertion and removal of two screens. The cover-plate anchoring ring should be fabricated

of 4- by 4-inch angle iron and should be embedded entirely in concrete, with only the steel hold-down bolts extending above the concrete surface. Plate hold-down bolts must be spaced at intervals no greater than 7 inches, and must be at least ¾-inch diameter to eliminate flexing of the plate and weakening of bolts by rust.

Pumping throughout the large tidal range creates a variable suction head as well as considerable variation in water temperature and salinity. In order to minimize these effects, the system was operated by intermittent pumping, which was as a rule done at any stage of tide higher than half-tide. This minimizes the danger of loss of prime of the pump, but does not completely eliminate it. Malfunction of the check valve regardless of the stage of tide is also a factor in loss of prime. Since funds were not available for an automatic vacuum system, we have used the fresh-water supply as a source of priming water. This is achieved by making direct connection between the main fresh-water line and the main sea-water line so that an adequate volume could be flowed directly into the pipe or built up in the storage tank to provide enough water for priming even when the check valve was stuck wide open. The pump control system is designed to be either automatic or manual. When lines were filled, repriming was accomplished by switching electrical controls from automatic to manual and allowing the pump to refill the storage tank.

In addition to the normal safety switches for protection of the pump motor in case of overload or low voltage, an interlocking safety switch and control system was designed. An ordinary mechanical float switch with styrofoam flotation was used in the main storage tank to prevent overfilling. A mercury switch, activated by air pressure and connected to an open-ended plastic pipe on the beach, was used to provide an adjustable tide-level switch. In operation, as the tide recedes below a predetermined level, this switch shuts off the pump so that pumping cannot occur, and as the tide rises, air pressure in the line reactivates the switch so pumping can occur on demand. To protect the hard-rubber-lined pump from being run without water, an electric probe switch in the suction screen box coupled to a relay provides positive protection against loss of prime and prevents automatic restarting of the pump following power outage. This loss-of-prime safety switch has not been entirely trouble free, but we have found in practice that as long as it is checked daily and cleaned occasionally, it provides adequate protection for the pump.

Sea-water storage facilities, as mentioned in the beginning, initially consisted of a single 10,000-gallon wood storage tank placed on a hill at an elevation approximately 6 feet above the roof of the laboratory building. When full, it provided a maximum head of about 15 feet. Since antifouling paints, or applications of toxic chemicals to prevent or remove boring organisms would also jeopardize other invertebrate animals, it was originally planned to treat the tank periodically with hot fresh water. However, the volume required to adequately treat the tank was so large (4,000 gal.) that it was impractical to use this approach. Partial protection was achieved by coating the bottom with high-melting-point roofing asphalt and the walls with bituminous water-tank paint. Later a polyethylene liner was installed to achieve better protection of the tank walls. In spite of these efforts, the walls became so riddled with teredos (*Bankia setacea*) that the tank had to be replaced after 7 years' operation.

A new 15,000-gallon concrete storage tank was built adjacent to the original wood storage tank. It was provided with

a concrete cover, the floor was properly sloped for adequate drainage and flushing, and a direct fresh-water connection was installed. Since no substance which we were sure was not toxic to invertebrate larvae appeared to be practical for sealing green concrete, we allowed the tank to leach out naturally in sea water. It is particularly important to note that "green" concrete had significant toxicity to Pacific oyster larvae for more than 9 months after the tank was completed.

In the course of conducting a 3-year bioassay on adult Olympia and Pacific oysters, additional sea-water storage capacity was needed. To provide this at a reasonable cost, we erected nine 5,000-gallon unpainted Douglas-fir storage tanks, which were lined with 4-mil polyethylene sheet. This made a generally satisfactory liner which prevented attacks by marine borers and provided proven nontoxic water contact surfaces. We found that the 4-mil sheet, unless very carefully handled, was subject to abrasion or cutting. After 2 years, replacement was made with shaped 8-mil polyvinyl-chloride liners. These liners were found to be toxic. At writing, we are still trying to determine what component of the liners was the source of the toxicity. In previous tests, solid polyvinyl-chloride fittings were nontoxic. We have to assume that some type of plasticizer used in the bonding of the seams or manufacture of the film may be the toxic agent.

Overhead feed lines have always been difficult to maintain in trouble-free operation. In order to solve this problem at Point Whitney, and provide easy cleaning, the aquarium distribution lines were 2-inch hard rubber with T or cross fittings in place of elbows at each turn. Instead of placing potentially troublesome valves on the ends of the distribution lines, a 2-inch neoprene radiator hose was clamped to the end of a hard-rubber pipe nipple, and the flow was adjusted by means of a wooden pinch clamp. Water flowed into 8-inch-deep open wooden header troughs running the length of each room. The header trough has an advantage in that holes may be bored any place along the trough to provide flow through glass tubes of constant orifice for individual or groups of aquariums or trays, the only limitation in capacity being the size of the distribution line itself. Even though marine plywood was used, teredos (*Bankia*) riddled the header trough and lower aquarium trays. The trough was coated with hot roofing tar, and the trays were rebuilt with polyester resin coating. This has been satisfactory.

Clearing sea-water lines of marine fouling organisms is a potential problem in any area where surface waters are used. At Point Whitney, common fouling organisms are mussels, barnacles, oysters, tunicates, serpulid worms, and sea anemone. In addition to reducing the rate of water flow, they also compete with experimental animals for food, and contribute metabolites to the water. At Point Whitney, provision was originally made both for cleaning by hot water and for mechanical removal. Several sources of hot water were tried, including domestic furnace, domestic hot water, recirculation of specially heated water, and a portable steam cleaner unit of the type used in automotive repair shops. None of these supplied enough heat to kill all fouling organisms throughout the lines. We finally obtained a 400-gallon heavy steel tank, mounted this over a firebox, and used it to provide a charge of boiling water of sufficient volume to completely fill each separable unit of sea-water intake and discharge lines. It has been satisfactory and economical to use, since thorough cleaning about twice a year is adequate. However, owing to the difficulty of removing salt water from the lower end of the

submerged suction line and replacing it with hot fresh water, we finally turned to the use of a mechanical pipe cleaner (Roto-rooter) which is used twice a year to ream out the line.

Three-quarter-inch flexible polyethylene pipe used in part of the system also became clogged with growing mussels. In time it became impossible to remove these mechanically or by hot-water treatment. We were forced to use concentrated hydrochloric acid in these lines to kill animals and partially dissolve their shells. Recovery of the hydrochloric acid has made this type of cleaning economical, and thorough flushing with sea water removed all traces of acid.

Shortly after the system was in operation, we found that the lower end of the sea-water line was being heavily pounded because of the sudden change in momentum of the water when pumping was stopped. A shock-absorbing effect was achieved by attaching 4-foot vertical 4-inch steel water pipes to the sea-water lines both ahead of and behind the pump. This cut down the water hammer, and no further damage from this cause has occurred.

In 1957, additions to the sea-water system were made which included wooden storage tanks mentioned before, and additional sea-water discharge lines to carry water to control, mixing, and delivery tanks for a long-range sulfite waste liquor bioassay. By this date, flexible polyethylene and semirigid Kralastic pipes and PVC fittings without plasticiser were readily available, and had been proven nontoxic in sea-water system use. We installed about 225 additional feet of 3-inch plastic sea-water line beyond the main storage tank, to an elevation approximately 20 feet higher than the previous maximum water level. Kralastic and PVC were joined with glue on the job without special equipment. Modifications or correction of errors were made simply by sawing the pipe off with a handsaw and inserting the correction with slipover couplings. This type of pipe has been impervious to fractures, climatic extremes, and chemicals.

The original water demand on the sea-water system at the time of initial construction ranged between 10,000 and 20,000 gallons of water per day. With increased use and extension of the system, demand increased to approximately 50,000 gallons per day. Throughout this period, the WEFM hard-rubber-lined pump originally described has been adequate to provide all the water required and still maintain intermittent pumping generally in the tidal ranges desired. It is anticipated that in our location this system could produce up to 100,000 gallons a day without enlargement.

We have found it essential to toxicity-bioassay, by means of marine invertebrate larvae, all of the component materials of the sea-water system, determine their degree of freedom from toxicity, and subsequently, bioassay quality of water supplied to experimental animals.

There are marked differences in growth, survival, and fatness of oysters held in the laboratory and those grown in the bay. We have found that oysters suspended near the surface do best, those grown on tidelands are poorer, and those in the sea-water storage tank are poorest. In each instance the groups of oysters tested had access to virtually unlimited quantities of water. Hydrographic data collected just beyond the intake shows stratification, during the period of highest water productivity, between surface waters and those normally tapped by the sea-water system. Chlorophyll values are also higher in the bay surface water than at either sea-water intake level or at point of entry into laboratory aquariums. These observations indicate that water

quality could be improved by means of a floating intake line positioned so as to pump water from the surface layer where water productivity is highest. Several difficult physical problems must be solved before this method would be satisfactory for our location, and as yet this component has not been built.

CONCLUSIONS

The sea-water system at the Point Whitney laboratory has provided satisfactory service when operational factors of this location are considered. Preventive maintenance by skilled personnel is a critical factor in maintaining this or any other sea-water system in continuous year-round operation. It is clear to us that a dual system using present-day nontoxic plastics would probably be more dependable, lend itself more readily to preventive maintenance, and be definitely easier to keep free of fouling organisms, than our present system. Inasmuch as funds are not likely to be available for the complete rebuilding of the system, modifications of the present system must be carefully engineered to utilize existing equipment so far as possible.

LITERATURE CITED

WESTLEY, RONALD E.
1956. Retention of Pacific oyster larvae in an inlet with stratified waters. Washington Department of Fisheries, Fishery Research Papers, vol. 1, No. 4, pp. 25–31.

SEA-WATER SUPPLY SYSTEM IN A SHELLFISH-CULTURE LABORATORY

By P. R. Walne

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Abstract.—The sea-water supply system of a set of laboratories devoted to the culture of bivalve mollusks is described. The water is distributed from roof tanks to a tank room where it is heated and enriched with phytoplankton, and to the hatchery where it is filtered and sterilized. The equipment used for heating, filtering, and automatically enriching with algal cultures is discussed.

The sea-water system described in this paper is used in a laboratory engaged in investigations on the culture of larval and adult bivalve mollusks. It is built on a site adjacent to a set of concrete tanks constructed 50 years ago for mussel purification, and the pumping facilities of these tanks are also used to deliver sea water into the main laboratory storage tank. The site is on the estuary of the river Conway, and suitable-salinity water is obtainable only for a few hours at high tide. Apart from this, some storage is desirable to reduce the silt content of the water which is liable to be high during rough weather.

The use of metals has been avoided as far as possible in the construction of this system. The largest amount of metal is the iron main through which the water is first pumped. From the results obtained, this seems to be quite harmless, but the continual addition of rust to the water is a nuisance at times.

GENERAL LAYOUT

The water is pumped up from the estuary by a centrifugal pump with cast-iron body and impeller driven by a 30-horsepower electric induction motor and is delivered (for laboratory purposes) through 6-inch cast-iron pipes into a 20,000-gallon reinforced-concrete tank at 40,000 gallons per hour. From the main outside storage tank the water is pumped as required through a 2-inch polythene pipe into a set of three interconnected 100-gallon fiberglass tanks in the roof of the laboratory block. Fiberglass tanks were chosen because of their lightness and freedom from corrosion, and after tests had shown that oyster larvae could be satisfactorily cultured in them. The pump, which is close to the wall of the main storage tank, is a 2-inch pump (Mono Pumps Ltd., London) with a stainless-steel rotor and a rubber stator and is sited below the level of the water in the tank. This is important in a pump under automatic control, since it eliminates trouble due either to failure of the pump to prime or, if a foot valve is used, to leakage due to dirt or organisms growing on the valve. The pump is controlled by a float switch (Stuart Turner Ltd., Henley-on-Thames) in the laboratory roof tanks which are thus automatically kept nearly full of water. As there is no foot valve on the pump, the pipe empties to the level of the water in the storage tank when the pump stops, and this prevents the growth of sedentary organisms in the pipe.

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From the roof tanks the sea water is distributed to all rooms by standard polythene piping. Throughout the laboratories the flow is controlled by polythene valves (Saunders Valves Co. Ltd., Cwmbran, Newport, Monmouthshire). These valves, in which all parts in contact with the liquid are of plastic, are diaphragm valves which are closed by depressing the diaphragm until contact is made with a weir in the pipe line. In the laboratories, a supply is piped to plastic-lined pillar taps fitted with Saunders valves. Elsewhere the lines end in threaded Saunders valves to which various pipe lines for different apparatus can be attached as required.

HEATED SEA-WATER SYSTEM

This system feeds a supply of warmed sea water into the tank room to stimulate spawning in oysters in the winter months. It is the most elaborate part of the system and is therefore described in some detail.

The general layout is shown diagrammatically in figure 1. The water is heated in a fiberglass tank which stands alongside, and is connected to, the storage tanks in the roof. As its top is level with that of the storage tanks no level-control valves are required. The water is heated electrically by three 3-kilowatt immersion heaters which are coated with fused silica (Vitreosil, Thermal Syndicate Ltd., Wallsend-on-Tyne). These heaters, which stand vertically in the tank, are made so that the heating element is in the bottom 17 inches of the heater. Because this part of the heater must not be exposed to the air when it is on, the inlet and outlet of the tank are above this level, and in the event of a pump failure or excessive drawing off of water the heaters cannot become uncovered.

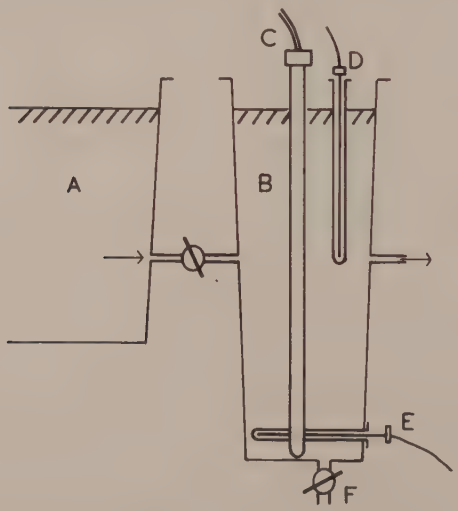

FIGURE 1.—System for warming flowing sea water: *A*, storage tank; *B*, warming tank; *C*, 3-kw. Vitreosil-covered immersion heater; *D*, thermostat in glass pocket controlling heater; *E*, safety thermostat; *F*, drain.

The heaters are controlled by bimetal thermostats (Sunvic T. S. 8, Associated Electrical Industries, London) inserted into a glass thermometer pocket fixed vertically in the tank. To improve heat transmission the pocket is filled with a heat transfer oil. The thermostat, which has a differential of 0.1° C., controls the heater through a hot-wire vacuum relay (Sunvic, Associated Electrical Industries, London). The basic heating is done by two heaters which are controlled by one thermostat, while the final control is given by a third heater controlled by its own thermostat. This allows the system to operate with 1, 2, or 3 heaters according to the requirements of the laboratory and the temperature of the incoming water, and avoids the disturbance to the laboratory electrical supply which might be caused by switching 9 kilowatts on and off. It is necessary to stir the water either mechanically or with compressed air; otherwise marked temperature stratification can occur.

As an additional safety measure, a thermostat in which the contacts close with rise of temperature is placed in a thermometer pocket fixed horizontally in the side of

the tank near the bottom—and therefore never liable to be uncovered. This thermostat, set at about 60° C., operates through a contactor which, when energized from the thermostat, interrupts the current supply to all the heaters. The supply can only be manually restored.

This tank, with a volume of about 150 liters, produces about 200 liters per hour of sea water at 22° C. from water at 2° to 4° C., and although there are regular fluctuations in the temperature of the water, as it leaves the tank, due to the switching of the thermostat and the time taken for the heaters to warm up, these are damped in the 40-liter aquariums into which water is running at 10 liters per hour. A flow rate of 200 liters per hour raised through 20° C. is about two-thirds of the maximum possible with an input of 9 kilowatts. This is an adequate margin for cold weather or exceptionally large requirements. The degree of temperature control given by this system is shown in the thermograph record from one of the aquariums, reproduced in figure 2.

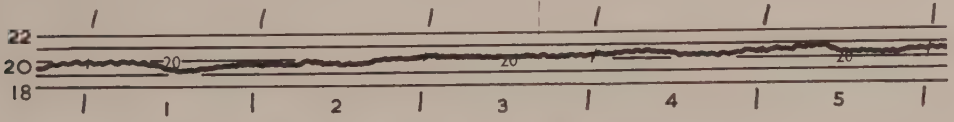

FIGURE 2.—Temperature record for 5 consecutive days in a 40-liter aquarium—flow rate about 10 liters an hour and the incoming temperature about 5° C. before heating.

The warmed sea water flows by gravity into the tankroom where, after it has been enriched with algal cultures, it is distributed by a polythene manifold to a series of aquariums. The water is enriched, usually with *Phaeodactylum* or *Dunaliella*, because in the winter months the natural flora of the water is at too low a level for filter-feeding animals which are being induced to grow and breed by raised temperatures.

The arrangement for continuously enriching the water is outlined in figure 3. The incoming sea water enters a wooden header tank through a hard-rubber ball valve (Dexine Rubber and Ebonite Ltd., Rochdale, Lancs.). This tank is at a higher level than the aquariums. Immediately above the header tank is a plastic tank which is filled daily with 20 liters of algal culture. This has to be stirred continuously to prevent settling of the algal cells. The culture leaves the tank through a tube set flush in the bottom to which is attached a rubber tube, which passes through a solenoid-controlled pinch clip (Londex Ltd., London), and then into the header tank. The culture, therefore, passes into the header tank when the solenoid is energized for a few seconds every 15 minutes—the length of time being adjusted so that the algal storage tank takes 24 hours to empty.

The timing device (fig. 4) has been constructed from a synchronous motor (Sangamo Weston Ltd., London), with a spindle speed of 1 revolution per hour. Four brass arms with adjustable points are attached to the spindle. A mercury tilt switch (I.A.C. Ltd., London) is arranged on a cradle with an adjustable arm so that each of the spindle arms in turn briefly touches the arm of the mercury switch and gives it sufficient tilt to allow the contacts to close. This opens the solenoid-controlled pinch clip for a period, the length of which is dependent on the adjustment of the contacts. The turbulence in the header tank provides sufficient mixing, and the following counts of the density of *Phaeodactylum* in the water entering an

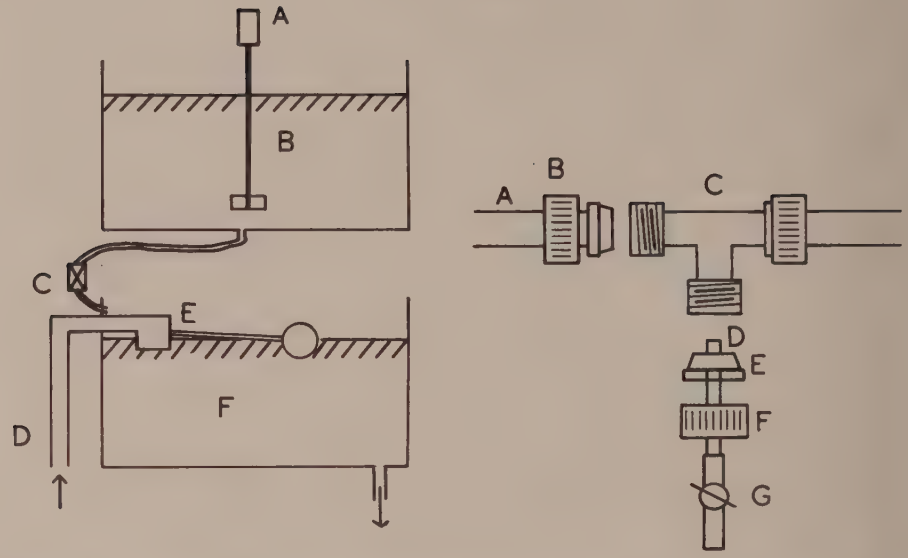

FIGURE 3.—Left—System for enriching the warm sea water with algal culture: *A*, stirrer; *B*, algal culture reservoir; *C*, solenoid-operated pinch clip; *D*, warm sea water supply; *E*, hard-rubber ball valve; *F*, header and mixing tank. Right—Detail of distribution manifold to aquariums: *A*, ½-inch polythene pipe; *B*, coupling nut; *C*, ½-inch polythene T-tube with screwed ends; *D*, glass tube; *E*, rubber stopper; *F*, coupling nut; *G*, Hoffman screw clip operating on a piece of rubber tubing.

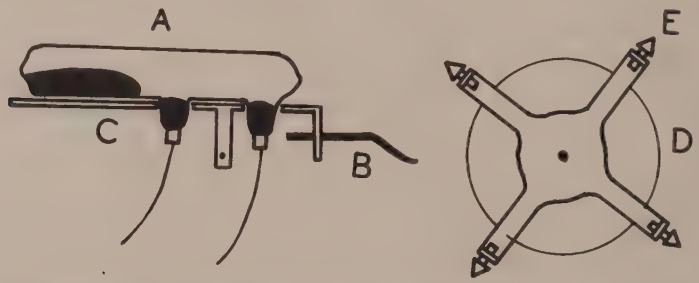

FIGURE 4.—Timing device for dosing algal culture into the sea-water system: *A*, mercury tilt switch; *B*, adjustable contact arm; *C*, brass cradle on a pivot; *D*, synchronous motor; *E*, 4 arms rotating at 1 r.p.h., each in turn making mechanical contact with *B*.

aquarium over a period of 15 minutes show the even amount of enrichment obtained:

Count of *Phaeodactylum* cells per cubic millimeter at—	
0 minutes	43
3 minutes	55
7 minutes	48
11 minutes	45
15 minutes	50

The enriched and heated water is distributed to the aquariums from a manifold made up of a series of T-tubes (fig. 3). The T-tubes and their interconnections are domestic cold-water polythene compression fittings (Plastronga, Yorkshire Imperial Metals Ltd.). As the flow rate is rather slow but continuous in this part of

the system, various organisms grow rapidly in the pipes and it is necessary to be able to unscrew the system easily for cleaning. The descending arm of the T-tube is fitted with a rubber bung held in place by a coupling nut. A glass tube is passed through the bung and a piece of rubber tube with a screw clip is fitted on to control the supply to individual aquariums.

It is necessary to hold the tankroom at a constant temperature in order that the rate of cooling in the aquariums shall be constant. The rate of flow is about 10 liters per hour into a 40-liter aquarium and, as the system produces water at a constant temperature, variations in the cooling rate can have a considerable effect on a tank. It is such changes that cause the gradual variations in temperature recorded in figure 2, which are, however, less than those recorded in most natural environments. While equipping each aquarium with its own heater, thermostat, and stirrer gives more precise control, the cost is very much greater. The writer has found that such an installation does not give any better results and to have so much equipment in each tank is a nuisance.

HATCHERY

The sea water in the hatchery is used for the culture of oyster larvae and for this purpose it needs to be free from suspended material and substantially sterile.

The water is first filtered by pumping through a pressure filter. The pump is a ⅜-inch plastic pump with a neoprene impeller and stainless-steel shaft (Cleghorn, Waring & Co. Ltd., St. Albans, Herts.). The pressure filter (Aerox Ltd., Glasgow) contains a cylindrical ceramic filtering element 10 inches long by 2 inches in diameter. The body of the filter is of vulcanite. It is desirable to interpose a coarse filter before the ceramic filter, as the latter can clog rather rapidly, particularly if there is a lot of phytoplankton in the water. After filtration, the water is sterilized by ultraviolet light using a 44-watt low-pressure mercury discharge lamp (Hanovia Ltd., Slough, Bucks.). In this lamp the water circulates between an inner quartz jacket containing the lamp and an outer glass jacket. This pump and filter unit pass about 300 liters per hour, a flow rate at which the ultraviolet lamp is able to kill more than 99 percent of the bacteria. The water is then passed directly via ½-inch polythene piping and Saunders valves to the larval culture tanks. It is also advisable to keep the piping from the ultraviolet lamp to the tanks as short as possible, since bacterial contamination can occur from the wall of the pipe, and bacteria which multiply on the inside of the pipe form a nucleus for recontamination.

SUMMARY

An account is given of a sea-water supply system in a shellfish-culture laboratory. Provision is made for heating the water to 22° C. and for continuous enrichment with algal culture.

AN AERATING DEVICE FOR SALT WELL WATER

By Donald W. Strasburg, *Fishery Research Biologist*

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Abstract.—Salt well water appeared to be a suitable medium for captive oceanic skipjack tuna except that the available supply was devoid of dissolved oxygen. A model aerating device, whose characteristics could be varied, was used to determine the features of a definitive aerator. The aerator was a tower containing 16 perforated horizontal trays spaced 2 inches apart; the well water was pumped to the uppermost tray, from which it showered successively through those beneath, becoming 95 to 100 percent saturated with oxygen when it reached the bottom. Skipjack were later maintained in this water.

A desire to increase the efficiency of capturing oceanic skipjack (*Katsuwonus pelamis*) has led the Bureau of Commercial Fisheries Biological Laboratory at Honolulu into a study of skipjack behavior. In addition to a high-seas investigation, the study has a shore phase in which skipjack are confined in ponds under controlled conditions. Because earlier attempts to establish skipjack in ponds were unsuccessful (Tester, 1952), a large amount of preliminary planning was undertaken in order to avoid what were regarded as pitfalls in the capture, handling, and maintenance of these sensitive fish.

Of utmost importance was the need for an abundant supply of clean, circulating sea water, preferably water of an oceanic rather than a littoral character. The Laboratory's dock and pond facilities are located in Kewalo, a Honolulu district with three sources of salt water: Kewalo Basin, the Pacific Ocean, and salt ground water (fig. 1). Although Kewalo Basin is immediately adjacent to the Laboratory ponds, its water was eliminated from consideration because of a variable contamination from industrial and maritime sources, and also because the small size of its water body might result in a drastic salinity drop during heavy rains. In addition, Kewalo Basin water is rather turbid, a condition deemed unsuitable for ecological and observational reasons. The cost of pumping Pacific Ocean water across 300 to 700 yards of reef and shore seemed prohibitive; also tending to eliminate ocean water were similar, if lesser, problems of contamination and dilution.

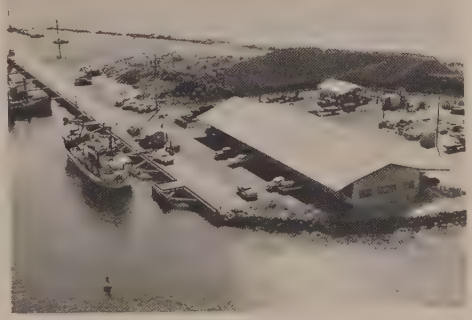

FIGURE 1.—Bureau of Commercial Fisheries dock facilities at Kewalo Basin, Honolulu, with the Pacific Ocean in the background.

Editor's note: Later developments of this system are described in the paper by Eugene L. Nakamura, which follows this one.

USE AND PROPERTIES OF WELL WATER

Because of the unsuitability of these sources, two salt-water wells were drilled at Kewalo in June 1958. The bores passed through hard-packed coral and sand to depths of 77 and 67.5 feet, of which the upper 42 feet were lined with 3½-inch casing (fig. 2). In November 1958, pumps

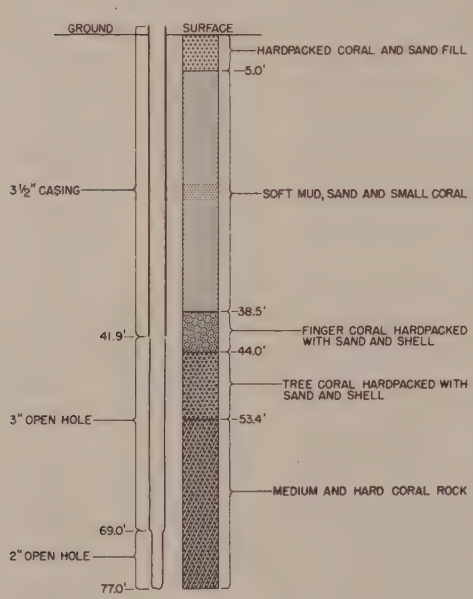

FIGURE 2.—Diagram of Kewalo well and surrounding stratigraphy.

were fitted to both wells, and studies were begun on the fitness of the water for maintaining various fish. Heavy pumping caused the shallower bore to become impacted with sand, but the 77-foot well has been in nearly continuous operation since that time. About 35 million gallons had been pumped in 20 months at rates varying from 30 to 45 gallons per minute. At these rates the drawdown of shaft water level was only 0.4 feet. Some properties of this water are listed in table 1, along with similar data for the Honolulu Aquarium well (3 miles from Kewalo) and oceanic water. The Kewalo and Aquarium samples were drawn on December 10, 1958, while the ocean water values were compiled from various sources, including the Honolulu Board of Water Supply. The analyses were performed by Y. F. Lee of the Honolulu Board of Water Supply, to whom I am indeed grateful.

The Kewalo and Aquarium samples differed from ocean water in chlorinity and pH, both items of concern to aquarists. The pH deficiency was easily remedied by heavy aeration of the incoming water, the pH value rising to 8.1 in about 40 minutes. The effects of brackish water on skipjack were unknown, but the slightly low salinity of the Kewalo water did not seem likely to be a serious problem. There remained to be determined, however, the salinity range to be expected following heavy rains and extensive percolation of pluvial water. Salinity and rainfall data are presented in figure 3, from which it is evident that rain had little diluting effect on the water supply.

Table 1.—*Some properties of Kewalo and Honolulu Aquarium well water and the nearby ocean*

[All values as mg./L. except pH]

	Kewalo	Aquarium	Ocean
pH	7.50	7.55	8.25
Silica	22	17	3
Calcium	400	438	405
Magnesium	1,211	1,251	1,315
Sodium	10,400	10,000	10,540
Potassium	365	375	400
Bicarbonate	144	137	
Sulfate	2,440	2,530	2,610
Chloride	17,800	18,400	19,150
Phosphate	0.10	0.10	0.20
Alkalinity [1]	118	112	115
Hardness [1]	5,965	6,225	6,400

[1] As $CaCO_3$ equivalent.

Conspicuously absent from table 1 are data on the dissolved oxygen in the well water. Winkler analyses of water direct from the pump gave oxygen values of 0.15 to 0.69 ml./L, the mean of 14 samples being 0.30 ml./L. This inadequacy was at first remedied by pumping the water over a perforated tray, from which it showered into a large tank containing reef fish. Al-

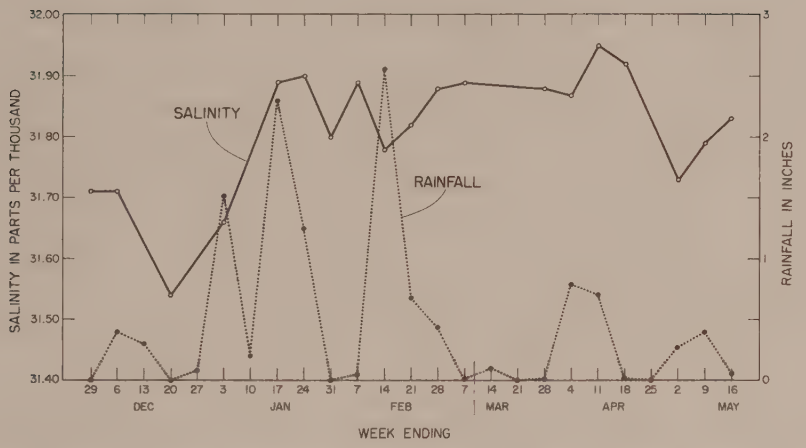

FIGURE 3.—Salinity of Kewalo well water and amount of rainfall at Federal Building, Honolulu, November 1958–May 1959. Rainfall data compiled by U.S. Weather Bureau.

though the oxygen content of this aerated water was as high as 2.34 ml./L, the fishes tested (*Abudefduf*, *Acanthurus*, *Arothron*, *Chaetodon*, *Parupeneus*, *Pervagor*, and *Zanclus*) did not thrive; in fact, many died within one or two days. In a closed-circuit control tank the oxygen level was maintained at 4.90 ml./L by continuous aeration with breaker stones, and here similar test fish did very well. It seemed obvious that an efficient aerating device must be an integral part of the pumping setup if circulating well water was to be employed.

AERATING DEVICES

A cursory survey of the literature plus correspondence with several aquarists revealed that little was known, or published, about the problem at hand. Specifically, a device was needed for bringing oxygen-poor water to the saturated state under high-flow conditions, and so constructed that oxygenation and circulation were concomitant features, eliminating any possibility of fish mortality from exposure to deoxygenated ground water. This requirement eliminated from consideration certain apparatus (Venturi systems, compressed gas liberators, and agitators) of great utility elsewhere (Norris et al., 1960). The field of choice was narrowed to sprays, cascades, and the like, where the influx of water per se results in aeration.

Plans for the aeration apparatus began to emerge when the physical conditions at Kewalo were considered. Beds of spraying fountains or shallow, baffled spillways were precluded by limited ground space, and the height of a tower from which water could fall was limited by the pumping pressure. Of various devices mentioned in the literature (Shaw, 1936; Betz Laboratories, 1957; McKelvey and Brooke, 1959), a compact block of stacked perforated trays seemed to be the most promising. Oxygen-free ground water would be pumped to the uppermost tray, from which it would shower successively through several lower trays, becoming saturated with oxygen just as it reached an aquarium below. The optima for tray spacing, number and size of tray perforations, rate of water flow, and tray number had yet to be determined.

EXPERIMENTAL AERATOR

To discover the interaction of these variables a model aeration device was con-

structed and a number of experiments were performed. Attention was focused on variations in dissolved oxygen resulting from different numbers and spacings of trays, while perforation size and number were held constant. Flow rate was necessarily low because of the miniature size of the equipment, but it was essentially constant at 182 to 193 milliliters per second (3 gallons per minute). Water temperature was also approximately constant, the range being 74.2° to 77.8° F. over the test period but with a fluctuation of less than 1 degree on any one day.

The apparatus assembled for a test is shown in figure 4; it consisted of the following parts: an open-faced wooden cabinet with a bottom drain and valve; an 11½-inch square wood and plastic inlet tray (actually an "under-gravel" filter) having 289 perforations and a brass nipple for attaching a hose; a number of 11½-inch square wooden trays having 144 perforations and no nipple; an ordinary ¾-inch plastic garden hose; a supply of metal C-clamps for positioning the trays in the cabinet; several sheets of thin vinyl plastic which were stretched across the face of the cabinet to prevent splashing; a short length of siphon tubing (not shown); and chemical equipment for determining dissolved oxygen by the Winkler method. In practice the flow rate, temperature, and amount of oxygen in the unaerated water were first measured, followed by the collection of samples from beneath varying numbers of equally spaced trays. The water samples were drawn from the bottom valve or by siphon; the drain was stoppered until 1 inch of water had accumulated in the cabinet's base, at which time a sample was taken.

Figure 5 shows the relations between tray spacing, tray number, and dissolved oxygen obtained from experiments with the model aerator. All oxygen values are shown in terms of percentage saturation

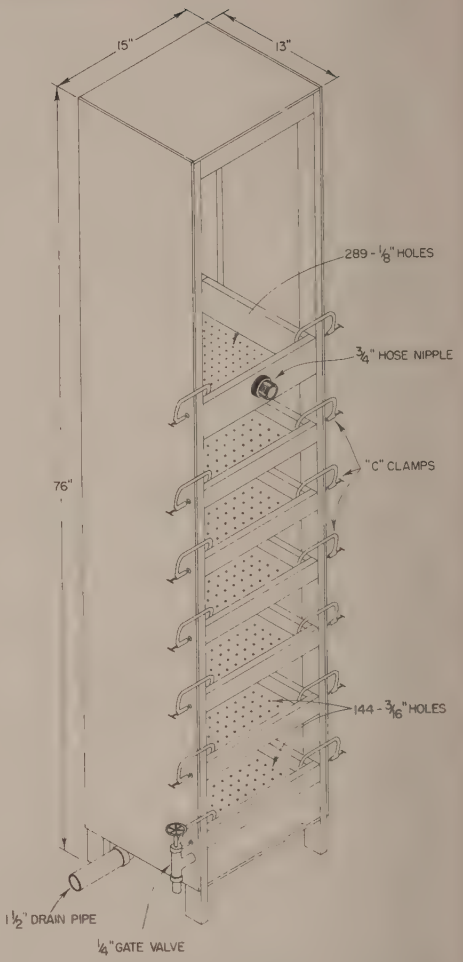

FIGURE 4.—Model aeration device used to determine effects of tray spacing and number on amount of dissolved oxygen in water. Water was supplied to the topmost tray by a hose attached to the nipple.

for the particular salinity and temperature prevailing at the time of the test (the percentage saturation was obtained from data presented by Sverdrup et al., 1942, p. 188). The curves were fitted by eye to coincide with the maximum number of points. Not shown in the crowded upper left portion of the figure are data from tests using 10 to 15 trays; the curves from these tests lay between those for 9 and 16

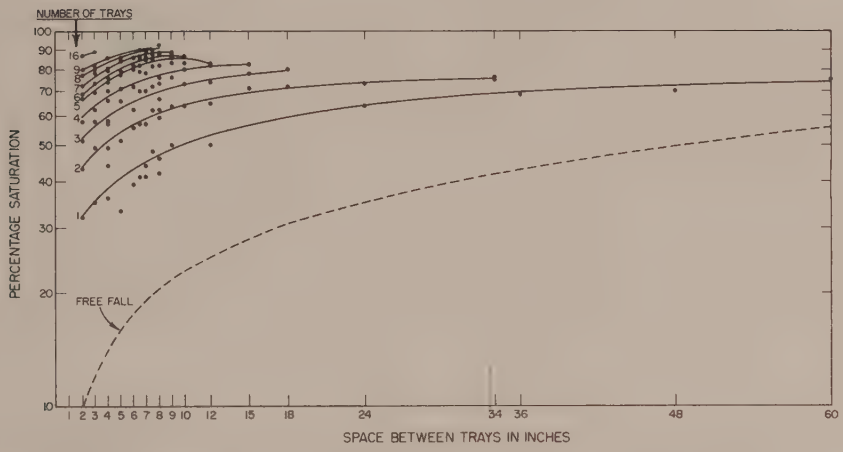

FIGURE 5.—Relation between percentage oxygen saturation, tray number, and tray spacing. Broken line represents time/distance relation for a body in free fall.

trays. Also not evident is the oxygen content of the incoming water; this ranged from 0.15 to 0.69 ml./L, but was most often 0.17 to 0.20 ml./L. The highest saturation achieved with the model aerator was 93 percent; the highest obtained by prolonged bubbling of air through the water was 96 percent.

Two aspects of figure 5 merit brief discussion. The first is the shape of the saturation curves: as is apparent, these have the general conformation of the curve describing the distance traveled by a freely falling body. Saturation is a function of the amount of exposure to air, and this varies with drop size, velocity, and height of fall. The left portion of each saturation curve is flatter than the corresponding part of the free-fall curve, undoubtedly representing additional exposure to air because of splashing, flow over the tray surfaces, or a velocity decrease caused by air resistance. Also contributing to the shape of the curves are such factors as water

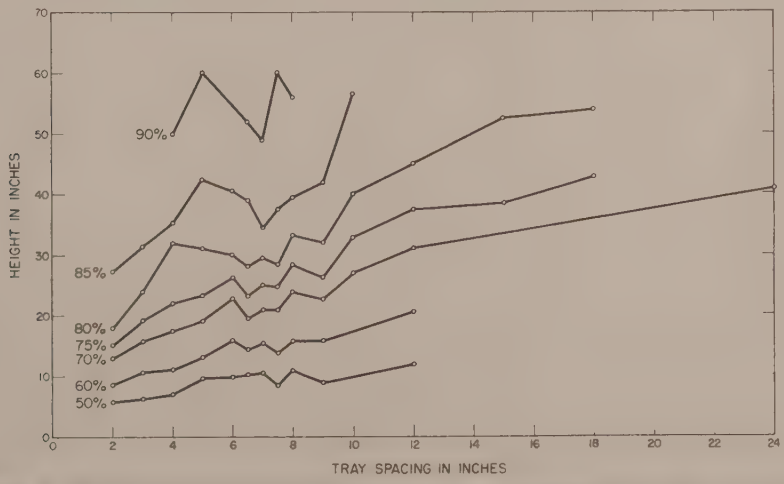

FIGURE 6.—Height of aerator needed to produce a given percentage of oxygen saturation.

films flowing down the cabinet walls, water drops falling cleanly through perforations aligned by chance, occasional stream-flow through a perforation, and the difficulty in adding oxygen to water as the saturation point is approached.

The second interesting feature of figure 5 is the relative importance of tray spacing versus number of trays. Although the same degree of saturation can be attained with either a few widely spaced trays or several closely spaced ones, there are practical considerations to be borne in mind when planning a definitive aerator. Wide tray spacing results in a tall aerator, requiring considerable pressure for pumping water to the top. Narrow tray spacing means a short device with numerous trays, the latter sometimes being expensive to construct and usually difficult to clean. Figure 6 shows the relative unimportance of tray spacing, for a con-

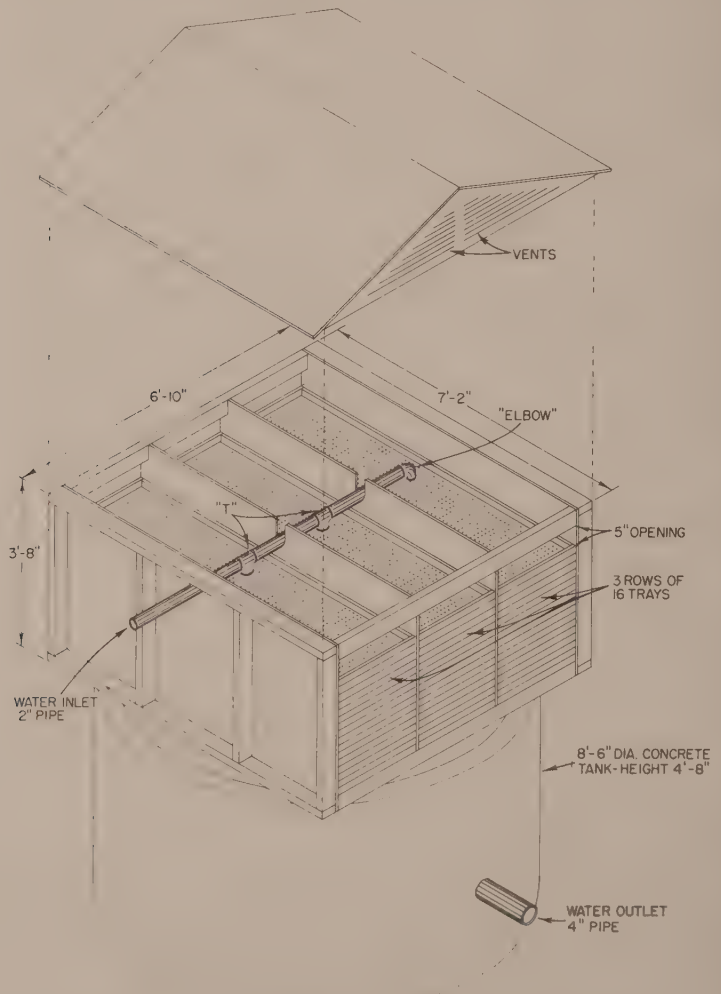

FIGURE 7.—Aerator developed for use with salt well water.

stant tower height, when only a low or moderate degree of saturation is desired. As higher degrees of saturation are attained, then the aerator becomes increasingly tall and spacing increasingly important.

DEFINITIVE AERATOR

Since it was desired to use highly saturated water as a medium for skipjack, some extrapolation was done from the upper curves of figures 5 and 6 in planning the definitive aerator. It was decided that 16 trays spaced at 2-inch intervals would provide near saturation with a moderate pressure requirement, and if these trays were perforated with ⅛-inch holes at ½-inch intervals there would be sufficient capacity to carry water at flow rates up to about 100 gallons per minute (and perhaps more). A diagram of the aerator ultimately built from these plans is shown in figure 7, from which the following features will be noted. The aerator is essentially a wooden box surmounting a concrete tank which receives the aerated water. The ends of the aerator are slotted for ingress of air, but light is excluded as much as possible to inhibit the growth of algae. Within the box are three rows of 16 long, narrow trays, which can be pulled out like drawers for cleaning or inspection. All construction is of wood except for the perforated tray bottoms, which are of pressed fibreboard doubly coated with an epoxy resin. The aerator has been in nearly continuous use for 18 months with only slight attention being required. Tray cleaning has not been necessary. Water passed through it ranged from 95 to 100 percent saturated with oxygen, and was successfully used for the maintenance of skipjack (see Nakamura, this collection).

LITERATURE CITED

Betz Laboratories, Inc.
1957. Betz handbook of industrial water conditioning (5th ed.). Betz Laboratories, Philadelphia. 254 pp.

McKelvey, Kenneth K., and Maxey Brooke.
1959. The industrial cooling tower. Elsevier Publishing Co., Amsterdam. 429 pp.

Norris, Kenneth S., Frank Brocato, Frank Calandrino, and William N. McFarland.
1960. A survey of fish transportation methods and equipment. California Fish and Game, vol. 46, No. 1, pp. 5–33.

Shaw, Paul A.
1936. Hatchery trough aerators. California Fish and Game, vol. 22, No. 2, pp. 126–136.

Sverdrup, H. U., Martin W. Johnson, and Richard H. Fleming.
1942. The oceans; their physics, chemistry, and general biology. Prentice-Hall, New York. 1087 pp.

Tester, Albert L.
1952. Establishing tuna and other pelagic fishes in ponds and tanks. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 71. 20 pp.

SALT WELL WATER FACILITIES AT THE BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU

By Eugene L. Nakamura, *Fishery Biologist*

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Abstract.—A salt well water system was developed in Honolulu to maintain skipjack tuna (*Katsuwonus pelamis*) in captivity. Problems encountered with the system included accumulation of rust from the cast-iron casing in the well, inability of the well to provide sufficient water for additional fish pools, inaccessibility of the aeration trays for cleaning, necessity of frequent cleanings of the fish pool due to algal growth, and inability to observe the fish closely because of wind ripples. These problems were remedied by drilling a larger well with an asbestos-cement casing, by building a new aerator with trays spaced farther apart and easily accessible, and by enclosing the new pool in a building.

A salt-water system was developed at the U.S. Bureau of Commercial Fisheries Laboratory's dock site in Honolulu in 1958 to maintain skipjack (*Katsuwonus pelamis*), a pelagic tuna, in captivity. Salt water from a well was used because of its freedom from sediments, pollution, dilution by rains, and fouling organisms (barnacles, mollusks, annelids, etc.). The system comprised a well, a pump, an aerator, a sump on which the aerator rested, and a fish pool (fig. 1). Polyvinyl-chloride pipes were used. The well, properties of the water, and the development of a suitable aerating device have been described in detail by Strasburg [preceding article in this collection]. While skipjack were being kept in the pool (Nakamura, 1960), certain shortcomings of this original system became apparent. These problems and their remedies are described in this report.

The casing of the well was a 3½-inch cast-iron pipe. Rust from this casing was deposited within the plastic pipes and on the perforated trays of the aerator. A layer of rust up to a millimeter thick lined the pipes after 18 months of use. Although rust was believed not to be harmful to the fish, it was undesirable because it reduced the bores of the pipes and the perforations in the trays and indicated deterioration of the well casing.

The limitations of the well's capacity became apparent when over 100 gallons per minute were pumped, for the water level in the well then dropped below the foot valve, which was 6 feet below the surface. This inadequate flow precluded the installation of additional fish pools.

It thus became apparent that a new well was required with a noncorrosive and nontoxic casing and of a capacity which should accommodate planned expansion.

The aerator was originally constructed so that the trays could be removed for cleaning. After about a year and a half of intermittent use, however, warping of the trays and swelling of the wood separating the trays made removal impos-

FIGURE 1.—Skipjack-holding pool, 23 feet in diameter and 4 feet deep. Behind the pool on the left is the aerator resting on the sump, and on the right is the pumphouse. The well, which cannot be seen, is between the pool and pumphouse.

sible. Since the trays were set 2 inches apart, the area between them was inaccessible for cleaning. Cleaning was desirable only because of the deposition of rust and not because of algal growth, which was inhibited by the enclosed situation of the trays within the aerator.

The aerator efficiently oxygenated the water (over 95 percent saturation), but did not adequately rid the water of carbon dioxide components. Excess carbon dioxide in the water caused the pH to be lower than that of normal sea water. The pH was 7.4–7.6 as compared with 8.1–8.3 in the open ocean (Sverdrup, Johnson, and Fleming, 1942). By rerouting the water through the aerator several times, the pH could be raised to 8.1 in 40 minutes, but this recycling was not practical.

In order to remedy these undesirable features of the aerator, plans for a replacement were made. The trays were to be spaced to permit cleaning. Better ventilation throughout the aerator was to be provided. Smaller but more numerous perforations were to be made in the trays so that the elimination of excess carbon dioxide would be improved.

The necessity of enclosing the pool in a building became apparent for two reasons. First, the entrance of direct sunlight into the pool could be controlled to reduce or eliminate algae. In the outdoor pool, algae grew rapidly, and frequent scrubbings

were required. Also, strands of a diatom (*Melosira* sp.) which broke off from the sides of the pool caused the water to become turbid. Second, the wind over the pool could also be reduced or eliminated. Wind ripples prevented clear observations through the water surface of the outdoor pool.

In August 1961 a new system was set into operation (fig. 2). The well is 73

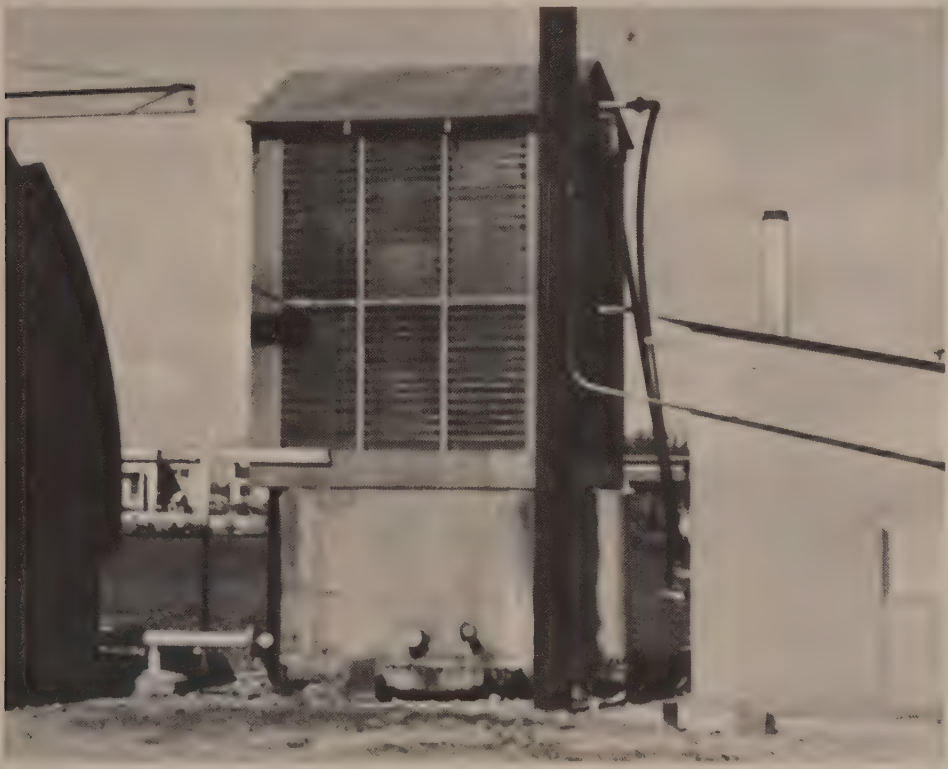

FIGURE 2.—Present salt-water system. The pumps and well are housed in the building at the right. The aerator, in the center, is resting atop the concrete sump. The fish pool is housed in the quonset hut on the left.

feet deep, cased with a 12-inch asbestos-cement pipe down to 42 feet. The depth of the well was determined by the depth at which 1,000 gallons of water per minute could be provided. The depth of the casing was determined by the depth at which hard coral rock was reached. Water is presently being pumped at 82 gallons per minute, but the well is capable of providing water at 1,000 gallons per minute with a drawdown of 6 inches. A centrifugal pump with a cast-iron housing and a steel impeller is being used because this type of pump happened to be readily available. Thus far, its performance has been satisfactory.

The aerator is 6 feet wide, 7 feet 9 inches long, and 10 feet high at its apex. All four sides have louvers. The two ends are hinged so that they may be opened for cleaning. It houses 16 aeration trays spaced 6 inches apart. The trays are made

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of laminated plastic, measure 1/10 by 72 by 51 inches, and are perforated by 1/8-inch holes spaced 1 inch apart. Water sprays onto the top tray from 1/8-inch holes in the sides of the 2-inch inlet pipe.

The concrete fish pool is enclosed in a quonset hut. Water flows by gravity from the sump into the pool.

This new system appears to be satisfactory. Rust is no longer a problem. The pH has been raised to 7.8–8.0. The trays are easily accessible by opening the ends of the aerator. There is practically no algal growth in the pool, and the observation through the water surface is excellent.

LITERATURE CITED

NAKAMURA, EUGENE L.
1960. Confinement of skipjack in a pond. Proceedings of the Hawaiian Academy of Science, 35th Annual Meeting, 1959–60. 24 pp. (Abstract).

SVERDRUP, H. U., MARTIN W. JOHNSON, and RICHARD H. FLEMING.
1942. The oceans; their physics, chemistry, and general biology. Prentice-Hall, New York. 1087 pp.

SEA WATER FROM GROUND SOURCES

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Abstract.—Efforts to obtain sea water from a ground-water source at the Sandy Hook Marine Laboratory are described. The basic theory of occurrence of fresh and salt water in coastal sand and gravel deposits is discussed and is confirmed by the results of a test well drilled at Sandy Hook. A hypothesis is advanced to explain both an unexpected reversal of salinity gradient and contamination by ferrous hydroxide. Although plans to maintain a continuous flow were frustrated, the water, after settling (to remove iron precipitate) has been used successfully in rearing 51 species of fishes and some invertebrates.

Many problems typically encountered in supplying large volumes of sea water to seaside laboratories can be solved by using a shallow ground-water source. The use of ground-water supplies involves a unique complex of problems, however, which must be anticipated before deciding in favor of a well system.

A major advantage of a ground-water supply is the elimination of barnacles, mussels, and other attaching organisms. These animals, which foul supply pipes and fittings, have no access to ground water. Also, sea water from a well is free from particulate contaminating material such as sand, silt, and detritus. Thus, filtration may be eliminated, and the design and construction as well as maintenance of the supply system may be simplified.

Another advantage of a ground-water supply is that physical characteristics of ground water remain relatively stable. Rapid fluctuations in salinity induced by tidal forces, which are so typical of estuarine or shallow bay waters, do not affect ground-water sources. The temperature of ground water is a function of average prevailing air temperature and, to a depth of 50 feet, is nearly constant for any location, varying a maximum of 1 degree annually. Therefore, ground-water temperature can be reliably predicted from air-temperature data (Collins, 1925).

A further advantage in using a ground-water source is that no special intake or pump support structures are required as for a direct sea-water source. These structures are often expensive and in many places are subject to damage by storms or, in northern locations, to damage by ice in winter. A well often may be located much nearer the laboratory than the inlet of a direct intake line, thus reducing cost and complications involved with lengthy transport lines.

We wish to express our appreciation to the U.S. Geological Survey (Trenton District Office) for their most helpful counsel and for arranging the analysis of our well water.

DESIGNING THE SYSTEM

This paper deals with problems encountered in obtaining sea water from subsurface sands and gravels at Sandy Hook, N.J. The decision to use a ground-water source for our sea-water supply was de-

rived from a combination of factors involving geologic characteristics of the area, location of the laboratory, storm effects peculiar to Sandy Hook Bay, the small amount of funds available, and the anticipated requirements of our experimental aquarium.

The Sandy Hook Marine Laboratory is located 160 feet east of the easterly shore of Sandy Hook Bay (fig. 1). The Sandy

FIGURE 1.—Sandy Hook Marine Laboratory; Sandy Hook Bay in foreground, Atlantic Ocean in background.

Hook peninsula is a post-Pleistocene development that resulted from deposition of sand and gravel by northerly long-shore currents which are interrupted by the outflow from New York Harbor and Raritan and Sandy Hook Bays. The average depth of waters surrounding Sandy Hook is about 20 feet. This permeable sand and gravel deposit hydraulically connected to the bay appeared to provide an excellent source of good quality sea water. A well supplying a continuous flow system could be located at the edge of the Bay near the source of the water and yet be only a short distance from the Laboratory. The plan consisted of the following:

1. A 4-inch-diameter polyvinyl-chloride (PVC) wellpipe fitted with a 4-foot-long PVC slotted intake screen (slots 0.014 inch in width) was to be inserted into a 6-inch-diameter (driven) iron housing and water-jetted to the minimum depth necessary to obtain sea water of full bay-strength salinity.

2. A nonmetallic submersible pump capable of a minimum pumping capacity of 20 gallons per minute was to be inserted into the 4-inch PVC pipe to maintain a continuous flow of sea water to the aquarium.

3. A 1¼-inch-diameter PVC transmission line to carry the water underground to the basement laboratory was to be run inside a 6-inch-diameter cast-iron housing.

4. A 3-inch-diameter PVC gravity-flow return line was to be run within the 6-inch iron pipe, the iron pipe to serve as protection for the re-

turn line and as an emergency overflow drain from the aquarium.

This plan for installing the well was achieved successfully, and except for a troublesome problem which was not anticipated—the presence of ferrous iron in the water source—would have adequately supplied our needs. This problem will be discussed in detail later.

THEORY OF SALT-WATER OCCURRENCE

In attempting to locate salt water, it was necessary to drill much deeper than had been anticipated. A series of test wells showed that, even at the very shore, with water level at 11 feet below ground surface, it was necessary to bore deeper than 40 feet to locate water of acceptable salinity. A similar situation is documented by Barksdale, Sundstrom, and Brunstein (1936) for ground-water supplies of the Atlantic City, N.J., region. Since this paper is difficult to obtain, relevant portions are given here.

The problem of obtaining fresh water from sands that are exposed for a part of their extent to the waters of the ocean has been studied in many parts of the world. The earliest scientific work on this problem was done in Europe, where the basic principles were first pointed out in 1887 by Badon Ghyben,[1] a Dutch captain of engineers, and in 1900 by Herzberg,[2] who appears to have had no knowledge of the earlier work. The basic principles that govern the relation of salt water to fresh water in a water-bearing sand have now been fairly well established. They are discussed by Brown in papers published in 1922[3] and 1925.[4]

At the contact between the fresh and salt waters the zone of diffusion is surprisingly narrow. In Holland, Pennink[5] found a range of salinity from 100 to 15,000 parts per million of chloride in distances varying from 60 to 100 feet. In the present investigation ranges from 800 to 8,000 parts per million and from 1,900 to 7,300 parts per million were observed in 4 feet of depth.

Salt water is heavier than fresh water and tends to fill the lower parts of a formation. The fresh water in the sand floats on the salt water much as ice floats on water, with most of its volume submerged. The position of the contact is determined by the head of the fresh water above mean sea level and by the relative specific gravities of the two waters. This is the principle developed by Badon Ghyben and Herzberg.

This theory is illustrated in figure [2, A and B]. | Figure [2A] shows a simple U-tube with both ends open to the air. The two legs of the tube are filled with two liquids of different specific gravities. The liquids in the tube will come to rest in such a way that the pressure at the bottom of one leg is exactly equal to and balanced by that at the bottom of the other leg. The surface of the lighter liquid will, therefore, necessarily stand higher than that of the heavier liquid. Furthermore, as the heavier liquid fills the lower part of the tube in both legs up to the level of the contact between the liquids, the pressure at this level is equal in both legs, and the heights of the two columns of liquid above the level of the contact are inversely proportional to the specific gravities of the liquids.

In a small island or narrow peninsula composed entirely of permeable sand and surrounded by sea water, this same balance of pressure occurs between sea water and the lighter fresh water. Figure [2B] represents a cross section of such an island and shows that the salt water not only fills the sand around the island but also extends entirely under it below the lens-shaped body of fresh water. In such an island, the resistance of the sand to the flow of water causes the fresh water from rainfall to build up a head above sea level sufficient to cause it to flow out into the ocean at the shores of the island. It also prevents the mixing of the salt and fresh waters in the sand below sea level by wave action. As the sand is permeable in all directions, the fresh-water head will cause a downward flow of fresh water until it fills the sand to a depth at which its head is balanced by the head of the salt water. When equilibrium has thus been

[1] Badon Ghyben, W. Nota in verband met de voorgenomen put boring nabij Amsterdam. K. Inst. Ing. Tijdschr, 1888–89, p. 21. The Hague, 1889.

[2] Herzberg, Baurat. Die Wasserversorgung einiger Nordseebader. Jour. Gasbeleuchtung und Wasserversorgung, Jahrg. 44. Munich, 1901.

[3] Brown, J. S. Relation of sea water to ground water along coasts. American Jour. Sci. 5th ser., vol. 4, pp. 274–294. 1922.

[4] Brown, J. S. A study of coastal ground water with special reference to Connecticut. U.S. Geological Survey, Water-supply Paper 537. 1925.

[5] Pennink, J. M. K. De "prise d'eau" der Amsterdamsche duin Waterleiding. K. Inst. Ing. Tijdschr., 1903–4, pp. 183–238. The Hague, 1904.

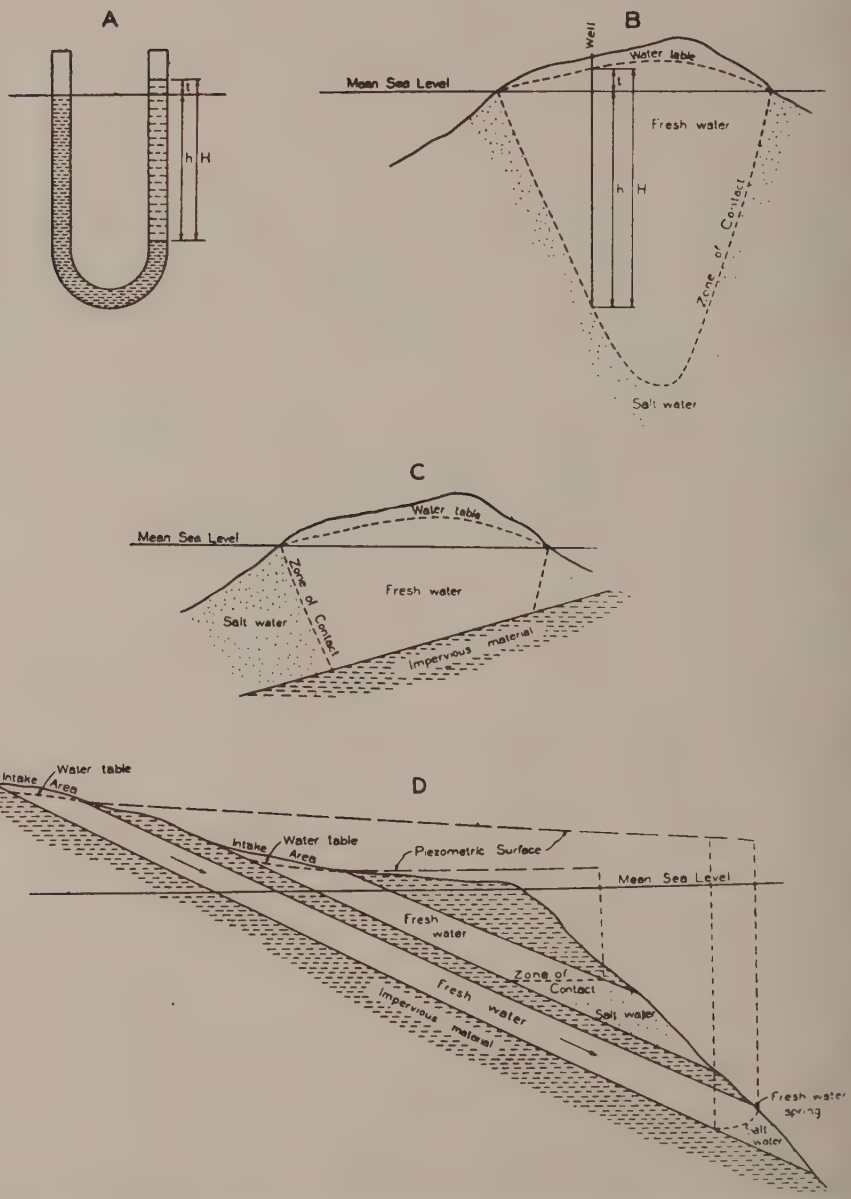

FIGURE 2.—Relation between fresh water and salt water in water-bearing sands when not disturbed by pumping: *A*, U-tube showing balance between two liquids of different specific gravities; *B*, section through an island composed entirely of sand and surrounded by salt water; *C*, section through a sand island underlain by impervious material; *D*, section through a coastal plain composed of alternate layers of pervious and impervious materials. (From Barksdale, Sundstrom & Brunstein, 1936—Supplementary Report on the Ground-Water Supplies of the Atlantic City Region; fig. 5, p. 26.)

reached, the depth of fresh water below sea level at any point on the island will be proportional to the fresh-water head above sea level at that point and the ratio between the depth and head of the fresh water will depend upon the relation between the specific gravities of the fresh and salt waters.

The following explanation, by Brown (1925, p. 16), of the relation between salt water and fresh water under a small sand island is applicable both to figure [2A] and figure [2B]:

Let H=total thickness of fresh water.
h=depth of fresh water below sea level.
t=height of fresh water above mean sea level.

Then $H=h+t$

But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Wherefore, if g is the specific gravity of sea water and the specific gravity of fresh ground water is assumed to be 1,

$$H=h+t=hg$$

$$\text{whence } h=\frac{t}{g-1}$$

In any case $g-1$ will be the difference in specific gravity between fresh water and the salt water.

If it is assumed that the specific gravity of sea water is 1.025, which is about an average figure, then $h=40t$. In other words, for every foot that the fresh water stands above sea level, it extends 40 feet below sea level. This ratio is so extreme that it is not practicable to show it in the various parts of figure [2]. For convenience, therefore, the first three parts of this figure have been drawn with a ratio of 1 to 10 between the head and depth of the fresh water. This would be the true condition if the specific gravity of the sea water were 1.100 instead of about 1.025. The fourth part of this figure is drawn with a ratio of 1 to 5 between the head and depth of the fresh water and represents an imaginary specific gravity of sea water of 1.200. The general relation between fresh and salt water shown by these diagrams is not affected in the least by this assumption of a specific gravity of sea water greater than the range that occurs in nature. The specific gravity of sea water varies from place to place, so that the figure of 1.025 used in the example above is only an approximate average.

In nature a body of land composed entirely of permeable material to any great depth is rare. The occurrence of beds or layers of impermeable material does not change the basic principles just discussed, but it does modify their application. If the island shown in figure [2B] were underlain by clay or bedrock that reached a level above the bottom of the fresh-water body, conditions such as those shown in figure [2C] would occur. Along the coast the position of the contact would be determined by the head of the fresh water, just as in an island composed entirely of sand, but under the center of the island fresh water would extend all the way down to the impermeable layer and would not be in direct contact with salt water.

The modification of conditions by impermeable formations is even more marked on the coasts of larger bodies of land, where water-bearing sands may lie under and between as well as above layers of impermeable material and may slope upward to remote intake areas well above sea level. Along such a coast the conditions in a permeable sand underlain by impermeable material would be similar to those in the sand island underlain by impermeable material, except that the fresh water would be in contact with salt water only on the side exposed to the ocean.

Figure [2D] shows two conditions which occur in water-bearing sands confined between layers of impermeable material. This diagram differs essentially from the others in that it shows the conditions that occur when the fresh-water in the sand is under artesian head rather than under water-table conditions. In the upper sand in this diagram, the salt water and fresh water are in balance, just as in the preceding examples. Salt water fills the lower part of this sand and fresh water fills the upper part of it. The position of the contact is determined by the head of the fresh water, which in turn is determined by the elevation of the intake area. The similarity between the conditions in this sand and those in the U-tube in figure [2A] is easily apparent.

In an artesian sand, the water is prevented from rising to the surface by the overlying impermeable bed. It is under a head that would cause it to rise in a well to a level above the bottom of the confining bed. The imaginary surface that would pass through the surface of the water in a well drilled to the sand at any point throughout its extent is called the "piezometric surface." The piezometric surface is therefore a pressure-indicating surface, and its elevation at any point indicates the head on the water in the sand at that point. At the intake area of the sand it merges into the water table which, though not imaginary, might be considered a part of the piezometric surface. In a section such as figure [2D] the line repre-

senting the piezometric surface is the hydraulic gradient of the water in the sand along the section. As there is no flow in the upper sand in this figure, the line representing the piezometric surface is level and extends from the intake area toward the ocean as far as the fresh water extends in the sand.

In the lower sand in figure [2D] the head of the fresh water is sufficient to cause a flow of fresh water into the ocean below sea level, forming a suboceanic fresh-water spring. The fresh water fills the water-bearing formation down to the bottom edge of the overlying impermeable layer and far enough below this level to permit the water to flow out into the ocean. Here again, the salt water fills the lowest part of the formation, but as the pressure in the main body of fresh water is greater than that in the salt water at the outlet, the salt water fills only that part of the formation in which the head of the fresh water has been reduced below the pressure of the salt water by the resistance of the sand to its movement. The line representing the piezometric surface for this sand slopes gently downward from the intake area to the point where the thickness of the sand carrying fresh-water is reduced by the intrusion of salt water. From that point to the point of discharge, the slope increases. . . .

Any general lowering of the head of the fresh water in a sand exposed for a part of its extent to the waters of the ocean will permit the salt water to advance farther inland and occupy more of the sand. The lowering may be caused by natural conditions, such as a dry year or a series of dry years, but lowering due to such causes is not likely to have any serious consequences, unless it occurs in conjunction with artificial withdrawal of water from the sand. This is usually accomplished through wells, either by pumping or by the natural flow from artesian sands. Pumping water from a water-bearing sand lowers the head of the water in it materially in the immediate vicinity of the point of pumping and, to a decreasing extent, for a considerable distance away. If this lowering of head or "cone of depression" occurs above or extends beyond the zone of contact, it will disturb the balance between fresh and salt water and permit the salt water to move up through the formation toward the well. The radius and depth of the cone of influence increase as the rate of pumping from the well is increased . . .

The specific gravity of sea water varies slightly from place to place and sometimes at different depths at the same place, but it is never much greater than that of fresh water. For the purpose of this report, the specific gravity of fresh water may be considered to be 1.000. In the summer of 1913, Bigelow [6] found that the specific gravity of the water off the Atlantic coast of the northern United States at different places and at different depths ranged from 1.019 to 1.028.

Owing to the very small difference between the specific gravity of fresh water and that of salt water, a slight change in the head of the fresh water produces a very considerable change in the position of the zone of contact. If a water-bearing sand is exposed to sea water having a specific gravity of 1.025, the level of the fresh water in it must be maintained at 2.5 feet above mean sea level if the zone of contact is to be held at a depth of 100 feet below sea level. A fresh-water head of 5 feet above mean sea level would be sufficient to hold back the sea water to a depth of 200 feet below sea level. Similarly, if the fresh water head in such a sand were lowered only 2.5 feet, it would permit the salt water to rise 100 feet. If the fresh water head in the sand were lowered to sea level, the salt water would rise to sea level. In a gently sloping confined sand, such as the upper sand in figure [3C], a vertical rise of 100 feet might represent a movement of the salt water several miles inland . . .

It has already been pointed out that salt water fills the sand around and beneath the lens of fresh water under a small island composed entirely of sand. The effect of pumping a well in such a sand island is shown in figure [3A]. As the depth of the zone of contact at any point on this island is determined by the head of the fresh water at that point, any lowering of the water table on the island would cause a rise of the salt water beneath the point where the lowering of head occurred. The section in figure [3A] is shown passing through a shallow well that is being pumped at a rate sufficient to draw the level of the fresh water down to a point somewhat above sea level. The cone of depression caused by pumping this well causes the salt water to rise from beneath the island in a shape similar to the cone of depression but inverted and proportionally much greater in its vertical dimension. This rise in the zone of contact might well be called a salt-water cone of elevation. The distance which the salt water rises is proportional to the amount of lowering

[6] H. B. Bigelow, Exploration of the coastal water between Nova Scotia and Chesapeake Bay, July and August 1913, by the U.S. Fisheries schooner *Grampus*. Harvard College, Museum Comparative Zoology Bulletin, vol. 69, No. 4, figs. 55, 61. 1915.

of the water table, and the ratio between the lowering of the water table and the rise of the salt water is determined by the relation between the specific gravities of the fresh water and the salt water. The position of the zone of contact beneath the island is not affected outside of the area of the cone of depression produced by pumping the well.

A lowering of the water table on the island by the pumping of a well will, of course, produce the same effect whether the well is shallow or deep. As long as the water table is not lowered to sea level, there will be a space filled with fresh water between the bottom of the cone of depression and the peak of the salt water cone of elevation. It is evident, therefore, that a shallow well on such an island might yield fresh water, whereas a deeper well at the same point and pumped at the same rate would penetrate the salt-water cone of elevation and yield salt water . . .

Figure [3B] shows the result of pumping water from a well on a sand island underlain by impervious material. A well very near the coast of such an island would, of course, encounter conditions similar to those in an island composed entirely of sand. Obviously, the safest location for a [fresh-water] well on such an island would be near its center. In this location a well might be pumped at a rate that would draw the water table down even below sea level without drawing in salt water, provided the cone of influence did not extend to any point at which it would be lowering the fresh-water head above the zone of contact. Under such conditions a "fresh water barrier" is said to be maintained between the well and the salt water. If the location of the well or the rate of pumping from it is such that the cone of influence extends beyond the zone of contact, the fresh-water barrier will be broken down, and salt water will be drawn into the well. The diagram shows the conditions that will occur when a well on the island is pumped at a rate which would cause its cone of influence to extend beyond the nearest part of the zone of contact. The salt water would move in under the island and form a cone of elevation beneath the well, similar to the one that would be formed on the sand island shown in figure [3A] except that it would be cut off at the bottom by the impervious layer. Here again a shallow well might yield fresh water, whereas a deeper well at the same place pumped at the same rate would yield salt water . . .

In an artesian sand the pumping of a well may not draw the head down to such a depth that the sand around the well is drained, as under water-table conditions. Usually pumping a well that taps an artesian supply merely lowers the head at and around the well and creates a cone of depression in the piezometric surface without unwatering any of the sand. Figure [3C] illustrates conditions under which salt water might be drawn into such a sand. In the upper sand in the figure a well in the part of the formation that contains salt water would, of course, yield salt water from the beginning. Salt water would be drawn into a well farther inland if the cone of influence of the well extended beyond the edge of the zone of contact. If the well were near the zone of contact, as shown in the diagram, this might occur with only a very slight lowering of the fresh-water head in the formation as a whole.

DEVELOPING THE WELL

From a shallow test well, we found the ground-water level at an average depth of 11 feet, and about 0.9 feet above tide level of the bay. Accordingly, with bay salinities ranging from 20 to 28 parts per thousand, depth of the fresh-water lens was estimated to be from 35 to 45 feet below the ground-water level or from 46 to 56 feet below the surface.

We planned to drill the well to a depth between 50 and 75 feet depending upon the quality of water located and the drilling problems encountered. Because of the fragility of the PVC pipes, the well pipe was water-jetted into place (within the 6-inch iron housing). This process utilizes a bentonite clay and water mixture. Consequently, in sampling the ground water for salinity as drilling proceeded, it was necessary to completely flush the sand of the clay-water mixture by extensive pumping of the well before drawing a sample.

The water, therefore, was tested for salt content at only a few intervals during the jetting operation. Jetting was terminated at 70 feet because of excessive loss of the bentonite mixture through a layer of coarse gravel (more than three-eighths

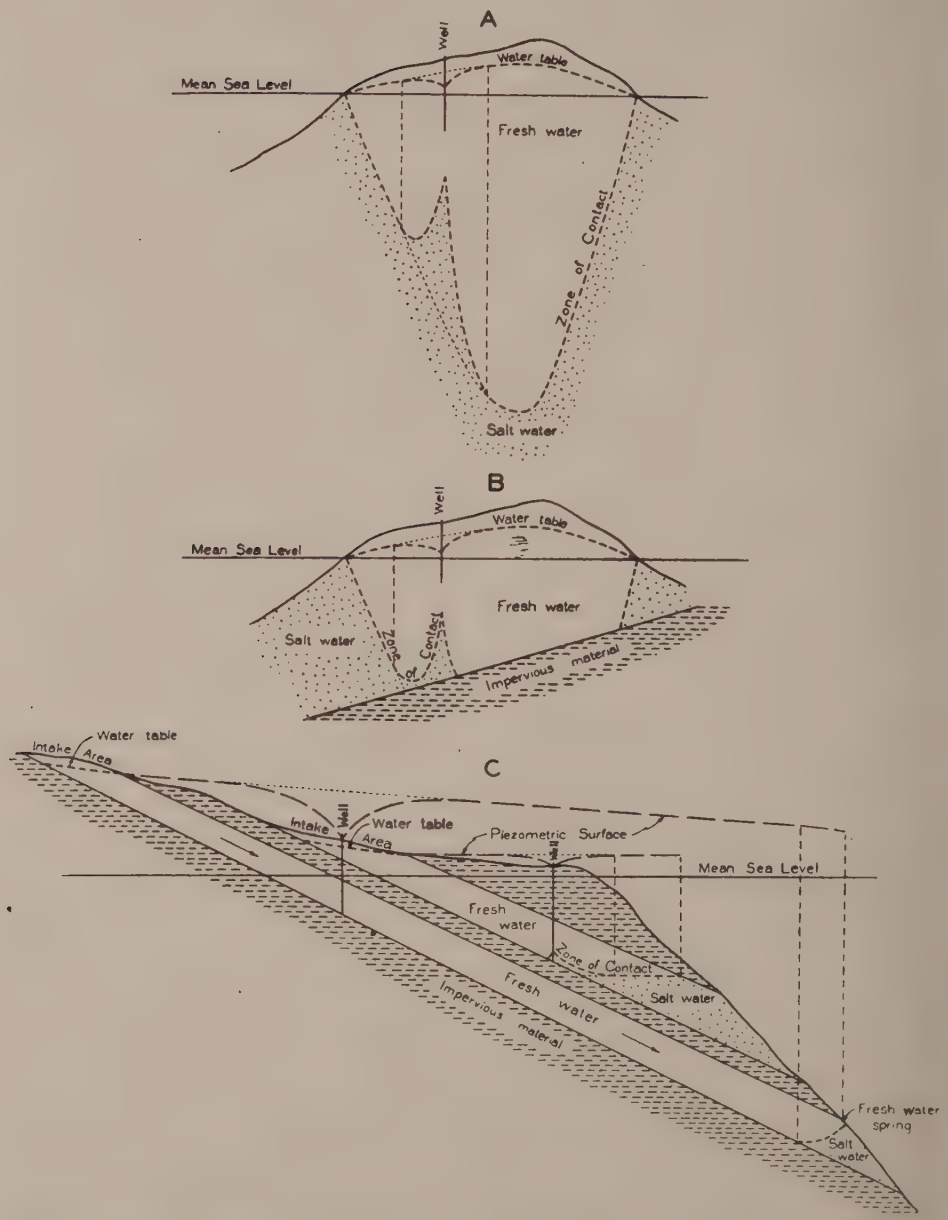

FIGURE 3.—Effect of pumping water from wells in sands exposed to salt water contamination: *A*, in an island composed of sand; *B*, in a sand island underlain by impervious material: *C*, on the coast of a large body of land where the water is confined between impermeable layers. (From Barksdale, Sundstrom & Brunstein, 1936—Supplementary Report on the Ground-Water Supplies of the Atlantic City Region; fig. 6, p. 31.)

inch in diameter) encountered at this depth.

Results of testing confirmed, in general, the theories of Barksdale et al. (1936) regarding depth of the fresh-water lens. This is shown as follows (average ground-water level 11 feet below surface; salinity of the bay 26 to 27 parts per thousand):

At depth of—	*Salinity of well water in parts per thousand*
11 feet	0
27 feet	0
52 feet	20
58 feet	25
65 feet	26
70 feet	23

However, the zone of diffusion was not as narrow as indicated by Barksdale et al. (1936). Another unexpected result was the reduction in salinity below 65 feet, indicating that fresh water was intruding from below, perhaps under artesian pressure resulting from the increase in elevation of the stratum toward the adjoining land mass. The effect of these factors is to confine the zone of higher salinity water to a relatively narrow band. The thickness of this band can be expected to change in response to changes in the salinity of the bay and the height of the fresh-water head above sea level.

On this basis, we decided to establish the well at 60 to 65 feet, but in raising the plastic well pipe from the point of maximum penetration (70 feet) to a shallower depth, the well screen became dislodged. In order to replace this screen, the casing was removed. Unfortunately, it could not be reinstalled to the same depth, and the well screen finally was established at a maximum depth of 57½ feet, where the salinity was only 1 part per thousand less than that of the bay (fig. 4).

After the initial flushing, the water, as it came from the well, was quite clear and appeared at first to meet all quality requirements, but within 4 hours following exposure of the water to air, a brownish-red precipitate appeared rendering the water unsuitable for our use without treatment.

The precipitate proved to be iron at a concentration of 4.8 parts per million, appearing as ferric hydroxide, $Fe(OH)_3$, which resulted from oxidation of soluble ferrous hydroxide, $Fe(OH)_2$.

In the Monmouth County area of New Jersey, iron contamination of potable ground-water supplies of fresh water is a familiar problem. In order to eliminate excessive amounts of iron in domestic water supplies, local communities commonly drill wells to depths of over 700 feet. Fresh-water supplies for Army installations at Sandy Hook are presently taken from wells of 500 to 900 feet in depth to avoid iron contamination, which is very often associated with sands of the Englishtown formation.[7] From logs of wells drilled at Sandy Hook, sands of the Englishtown formation appear to range from 120 to 170 feet below land surface and are underlain by sand and sandy clay to a depth of about 230 feet, which in turn is underlain by clay strata. In places, this clay is a solid, impermeable layer 10-feet thick. This indicates that the source of iron contamination of the sea water supply is from the Englishtown formation above the 230-foot clay layer. Since it is unlikely that iron would occur in the shallow, recent sands (in which the well screen is located), it may be that iron-bearing water is being forced up from the Englishtown formation. The pressure could result from a standing head of water developed over the clay in the adjoining land mass because the strata slope rapidly upward towards the shore.

This is the only explanation of the salinity reversal which appears compatible

[7] The Englishtown formation of late Cretaceous age consists of tan and gray quartz, fine- to medium-grained sand, locally containing beds of clay (Seymour Subitzky, personal communication).

with the explanations of Barksdale et al. Unfortunately, no funds are available for further explorations. A possible solution to be investigated when funds are available is to obtain water from a shallower point than the present 57½ feet. According to Seymour Subitzky of the U.S. Geological Survey, there is some hope that the amount of ferric iron in solution may decrease rapidly above the point of maximum salinity which is at full bay strength. The upper level of the influence of in-

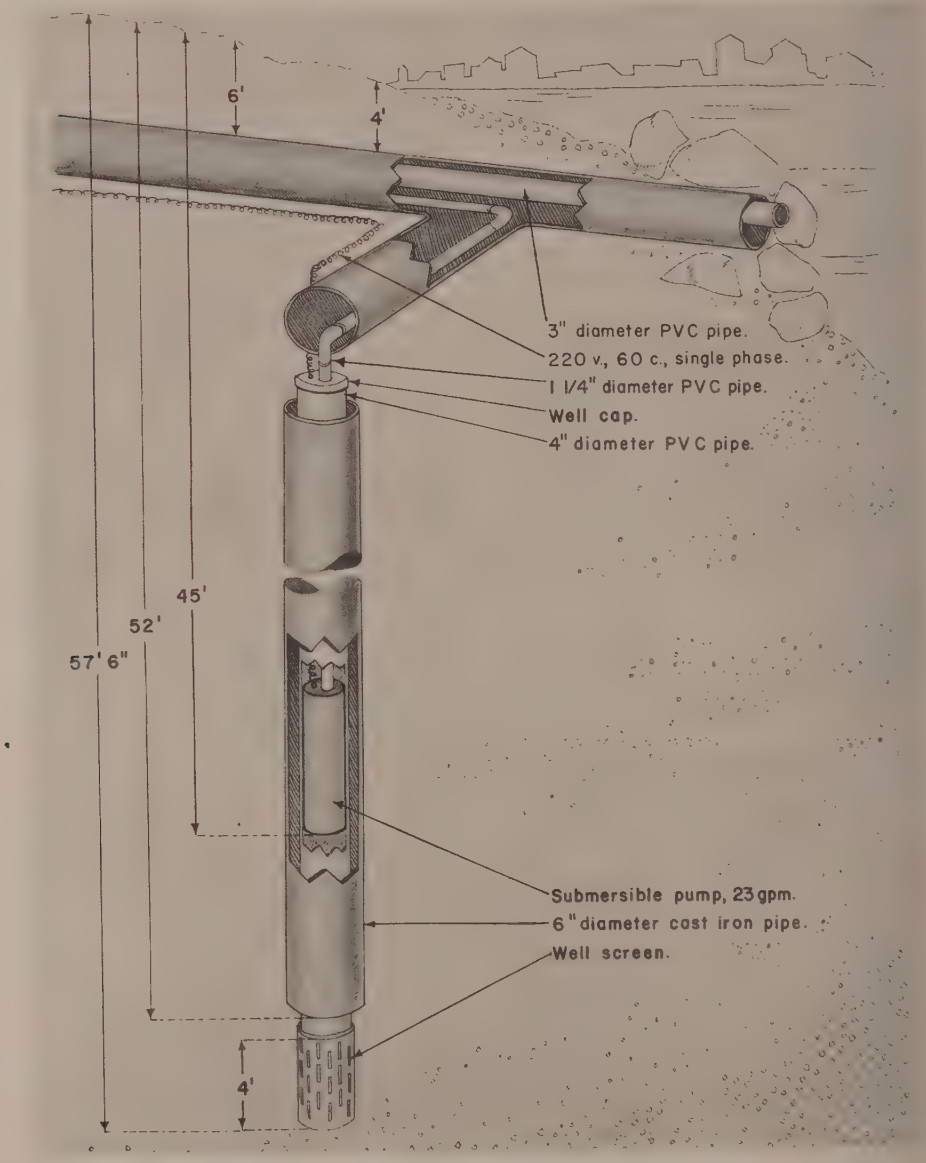

FIGURE 4.—Sea-water well installation at the Sandy Hook Marine Laboratory.

truded iron-bearing water may be associated with the upper level of the coarse-gravel stratum in which the well screen is now located. We hope to relocate the well screen at a higher point where we may find sea water of acceptable salinity, but with a ferrous iron content below the precipitation threshold—about 3 parts per million.

Although we have not tested the production capacity of the well, it can be assumed that the present installation, with a larger pump and transmission line, could produce nearly 100 gallons a minute without excessive drawdown.

CHARACTERISTICS OF THE WELL WATER

In order to use the well water, it is necessary to allow the ferric hydroxide to settle. This has been accomplished by holding batches of water in a 2,000-gallon tank. Since the flocculate is very light, requiring a week or more from time of oxidation to settling, this is a slow process. After settling, however, the water has been used successfully to rear eggs, larvae, juveniles, or adults of 51 species of 31 families of fishes. No failure to maintain any species of fish can be attributed to the quality of the decanted water. Many groups of invertebrates (ctenophores, coelenterates, mollusks, echinoderms, crustaceans) and several species of algae also have been successfully maintained in the well water. The following analysis of the well water (March, 1962) shows that after precipitation no iron remains in solution:

	Parts per million
Fe in solution, after settling	0.00
Mn in solution, after settling	.19
Fe, before settling	4.8
Mn, before settling	.29
SiO_2, before settling	8.8
Chloride, before settling	10

The temperature of the well water, taken during the occasional pumping intervals between September 1961 and March 1962, has remained at 56.3°±0.2° F. Unfortunately, owing to the settling procedure, the constant temperature factor is lost and room air-conditioning is used as a substitute. When the water is ready for use after settling, pH ranges from 7.6 to 8.1, dissolved oxygen is about 6 p.p.m., and specific conductance 28,500 micromhos (at 25° C.).

DISCUSSION

In view of its many advantages, it is suggested that the use of a ground-water source of sea water be explored when planning a supply system for any seaside laboratory. The feasibility of a ground-water supply will depend upon local conditions, and few generalizations can be drawn. Generally, if underlying earth material is uniformly permeable and extends laterally to the surrounding sea water, a sufficient supply can be obtained by penetrating to a depth beneath the fresh-water layer overlying the sea water. There remains, as a major problem, the possibility of chemical contamination of the ground-water source.

Except for the iron problem, Sandy Hook is an ideal location for a shallow salt-water well. In many other areas also, ground sources are used to supply aquariums. One example is the well, described in two papers in this collection (Strasburg, Nakamura) which was drilled into a coral formation in Honolulu. There is also a well in use at the Waikiki Aquarium in Honolulu. Spencer Tinker, Director of the Aquarium, has given us the following information about this well:

> The Aquarium stands on the edge of the ocean just a few feet from the water. The land under the Aquarium is loose unconsolidated rubble, sand, etc., to a depth of 40 feet. From 40 feet downward for an unknown distance there is an ancient coral reef which is quite solid but which contains scattered sand pockets and which is permeated by sea water. The Aquarium bored a hole in this area 80 feet in depth. This hole is larger than a foot in diameter and has the upper 40 feet cased with a 12-inch wrought-iron pipe. This pipe or casing keeps the rubble from

caving into the well, but there is no casing in the lower half of the well where the hole enters into the ancient coral reef. The water from the buried coral reef enters the lower open part of the well and rises up the casing and stands at tide level. The Aquarium pumps this water out of the casing and it continually replaces itself from the coral reef beneath. This 12-inch well cost $1,600 and took about 4 or 5 days to drill. We pump 500 to 600 gallons a minute from it, but it will yield in excess of 1,000 gallons. When the pumping rate approaches 1,000 gallons a minute, the drawdown approaches 2 feet. The quality of this water is good. It is absolutely clear, without larvae of any kind, free from seaweed, and makes us independent of storms and tides. It is more saline than the water on the shoreline and compares in salinity with the water far at sea. It is about 1° or so cooler than the shoreline water. Its great disadvantage, if this be one, is that it contains no oxygen. The oxygen in this water measures about 0.1 cc. per liter. This, of course, is insufficient for any biological work. We do imagine, however, that this lack of oxygen may prolong the life of various things that rust. To restore the oxygen into this water, we let the water draw in air as it comes forth from the valve above the fish tank. This simple act lifts the oxygen content to about 2.5 cc. per liter. This is not enough, perhaps, but it gets better with use and aeration.

These wells can be drilled close together. Eight or ten feet apart is sufficient distance to provide a well of the same capacity as the first one. These can be drilled into lava rock as well as into the coral reef.

The New York Aquarium on the beach at Coney Island also uses a ground-water supply. All attempts to pump water directly from the sea have been abandoned in favor of two 12-inch-diameter wells drilled to a depth of just over 200 feet, into a stratum of coarse gravel which provides excellent sea water. Each well is capable of producing 600 gallons a minute. The major problem associated with the Coney Island wells is that the water must be oxygenated. The New York Aquarium, which is about 7½ nautical miles north of the Sandy Hook Marine Laboratory, has no iron problem with its wells.

Efforts to locate a subsurface source of sea water at the Miami Marine Laboratory were unsuccessful (see Wisby, this volume) because of contamination of the ground water by H_2S.

At the time of writing, the Narragansett Marine Laboratory at Kingston, R.I., was in the process of developing a ground-water supply of sea water. The plans for this system called for a series of collecting wells from which the water was to flow by gravity through pipes to a central pump well. The water was to be pumped from the central well to a storage tank from which the aquariums were to be supplied by gravity.

EQUIPMENT SUPPLIERS

The major suppliers of components of our sea water system are listed below:

Submersible pump—Model 75 K1–5Ca (This model contains some metallic parts and is in use temporarily until the all-plastic model, 75 M1–5Cb, becomes available): Red Jacket Mfg. Co., Davenport, Iowa.

Water-supply pipe and fittings—Kraloy Type II, Schedule 80, pipe and fittings (3-inch-diameter, thick-wall, threaded PVC pipe and 1¼-inch-diameter PVC pipe): Kraloy/Chemtrol Co., Santa Ana, Calif.

Drain line and fittings—"Tuftite" PVC Plastic Sewer and drain pipe (During the course of our well-drilling operation we changed from the aforementioned Kraloy/Chemtrol Company to this manufacturer for the following reasons: (*a*) A branch office located nearby, therefore involving lower shipping expenses, and (*b*) a wider selection of material, particularly fittings. Lower prices. All pipe and fittings could have been obtained from this source.)

Well screen: Gator Sales Co., Shreveport, La.

LITERATURE CITED

Barksdale, H. C., R. W. Sundstrom, and M. S. Brunstein.
1936. Supplementary report on the ground-water supplies of the Atlantic City region. New Jersey State Water Policy Commission, Special Report 6. 139 pp.

Collins, W. D.
1925. Temperature of water available for industrial use in the United States, U.S. Geological Survey, Water-Supply Paper 520–F.

PRACTICAL SUGGESTIONS FOR CONSTRUCTION AND MAINTENANCE OF LARGE-VOLUME SEA-WATER SYSTEMS

By John T. Hughes, *Marine Biologist*

Massachusetts Division of Marine Fisheries, Vineyard Haven, Mass.

Abstract.—A brief description is given of a sea-water supply system in use in a lobster hatchery and research station in a region where the winters are severe. Two electrically driven pumps supply a maximum of 900 gallons per minute to an overhead tank holding 15,000 gallons. The water flows by gravity to station aquariums. Thirty-four concise suggestions are presented to allay problems of fouling, siltation, equipment breakdown, and toxicity.

The Commonwealth of Massachusetts built a sea-water system in 1948 to supply water to the new lobster hatchery and research station located in Oak Bluffs on the island of Martha's Vineyard. The salt-water system supplying the station consists of two 450-gallons-per-minute cast-iron centrifugal pumps, each with its own 6-inch plastic suction line and cross-valved so that both pumps can use either suction line. The suction lines are approximately 400 feet long lying on the bottom of the sea, with the foot valve supported 5 feet off the bottom in 10 feet of water. The foot valves are kept off the bottom by lashing them to pilings, the tops of which are below the surface of the water at the lowest tide level in order to prevent the ice from moving them in the winter.

Just before the suction lines enter the pumps, each line has a basket strainer to catch mussels or other fouling organisms which might plug the pump impeller. The pumps alternate in filling the storage tank when the water level drops 3 feet. The pumps are electrically driven; one pump is made so that it can be coupled to an auxiliary gasoline engine. The water is pumped into a cylindrical 15,000-gallon steel tank which is supported 15 feet off the ground. The water then passes to the station by gravity through a 6-inch pipe from which 2-inch lines lead to the various tank systems.

The following is a list of methods and features which are suggested, on the basis of our experience, to combat problems, such as fouling, siltation, equipment breakdown, and toxicity of components.

1. After one has carefully figured out what size pipe and pump will be necessary to supply sea water to an installation, double the size of everything.

2. Install one more pump than is necessary to take care of all possible emergencies.

3. Have a separate suction line for each pump and have each suction line cross-valved (with good high-pressure valves) so that any suction line may be used with any pump.

4. Use plastic pipe for suction and discharge lines. Use no pipe with copper.

Contribution No. 10 of the Division of Marine Fisheries, Massachusetts Department of Natural Resources, Boston, Mass.

5. Use flanged fittings with brass or stainless-steel bolts and neoprene washers.

6. Use tees for elbows, crosses for tees, and have flanged unions in every line.

7. Make positive that there are no air leaks on the suction side of the pumps.

8. Any pilings used to support pipe in the water should have their tops a few inches below low-water mark to prevent the ice from removing them.

9. Mussels can be killed by closing off a suction line for a few weeks and using another line. (No steam can be used with the plastic pipe of today.) No chemicals should be used to kill fouling animals.

10. Use no lead- or copper-base paints in tanks. Use only plastic-base paints.

11. Pump to a storage tank, and feed station by gravity.

12. Have the line leading from the storage tank to station 2 feet above the floor of the storage tank.

13. Use fiberglass tanks and holding units.

14. Do not use lindane or similar insect sprays.

15. Install an emergency generating plant to take care of lights and a minimum of one pump.

16. Have one pump capable of being coupled to a gasoline engine.

17. Have an emergency bypass from one pump to station without going through the storage tank.

18. Have as short a suction line as possible. Pump from a sump which is fed from deep water through a 5-foot pipe.

19. Have an automatic alarm system to warn of low water in storage tank. Telephone lines can be rented to ring an alarm in several isolated homes or offices.

20. Have gages on suction and discharge sides of pumps to indicate pump failures and breakdowns.

21. To clean growth from insides of some pipes, tie old tire chains on a rope and pull through. Have a rope on both ends so that the chain can be pulled back if it gets stuck.

22. Use as few values and fittings on suction side of pump as possible, and those used should be of high grade.

23. Have a basket strainer on suction line just before pump to catch detritus and mussels that would otherwise get plugged in pump impellers.

24. Use circuit breakers instead of fuses.

25. Drill ⅛ inch holes in the flapper of the check valve on the discharge side of the pump so that enough water can pass back through the pump rather than through the packings.

26. Put as few pipes as possible under the ground.

27. Make the frost-proofing boxes easy to take apart.

28. When passing through a bulkhead, overhead, or floor with a pipe, leave plenty of room to disassemble, particularly when through cement.

29. Make sure electrical system has a good ground, and protect from lightning.

30. When installing drainage system, use a few crosses with blank faces for future additions.

31. Have plenty of pitch to the floor toward drains.

32. Do not cover with cement the pipes that are to be used for heating or cooling water.

33. Use the type of pipe supports that can be easily taken apart and reused.

34. Where Y-type sediment strainers are to be used, have them made of plastic (PVC) pipe and perforated sheeting. Sediment strainers should be three times the size of the pipe on which they will be used.

NARRAGANSETT MARINE LABORATORY SEA-WATER SYSTEM

By Charles J. Fish, *Director*
Narragansett Marine Laboratory, University of Rhode Island, Kingston, R.I.

Abstract.—The stormproof sea-water supply and distribution system of the University of Rhode Island's Narragansett Marine Laboratory comprises six intake wells along the shoreline, a pump well, a pipeline to an elevated receiving tank, and a distributing pipe system from tank to laboratories. The system delivers about 120 gallons a minute during pumping periods.

Installation of a salt-water supply and distribution system on the Narragansett Bay Campus of the University of Rhode Island has been complicated by (1) its easterly exposure which in the past necessitated frequent storm damage repairs, and (2) seaward runoff of fresh ground water in the upper bottom layer which precluded use of well-points for intake filtration. Filtration has been found necessary in the bay to prevent fouling growth in the pipes.

To overcome these obstacles the present stormproof system has been devised during the past year and is now in successful operation. Grateful acknowledgment is made for the valuable services of Mr. Clarence Ebaugh, Consulting Engineer, whose examination of the beach fronting the property established that an adequate supply of Bay water would percolate freely through the sand and gravel bottom sediment to his recommended porous intake pipe and well, and Mr. Walter Caccia, University Hydraulic Engineer, who modified the original shoreline installation plan, designed the balance of the system, and supervised its installation.

Contribution No. 7 from the Narragansett Marine Laboratory of the University of Rhode Island.

As shown in figure 1, the system consists of four major divisions, a unit of six intake wells, a pump well, a Transite pipeline leading from the pump well to an elevated receiving tank, and a distributing pipe system from the tank to the laboratories.

Each of the six intake wells (fig. 2) consists of a cylindrical Transite pipe within a larger pipe of the same material, with the annular space between the two filled with graded crushed stone to act as a filter. The external piping is 36 inches in inside diameter and perforated with 1-inch holes on 3-inch centers. The inside piping is 10 inches inside diameter with ¼-inch perforations on 2-inch centers. This inner pipe collects and conducts the water from the crushed-stone filter to the manifold leading to the pump chamber.

In installing the intake wells the following steps were taken: (1) Building of a seaward sand and gravel barrier dike sufficiently offshore to permit dredging a crater to a depth of 12 feet, (2) arranging the work schedule to coincide with the time of the falling tide and period of low water, (3) providing sufficient pumping capacity to drain the crater as fast or faster than the fall of the tide, for maintenance of a water-free excavation, and (4)

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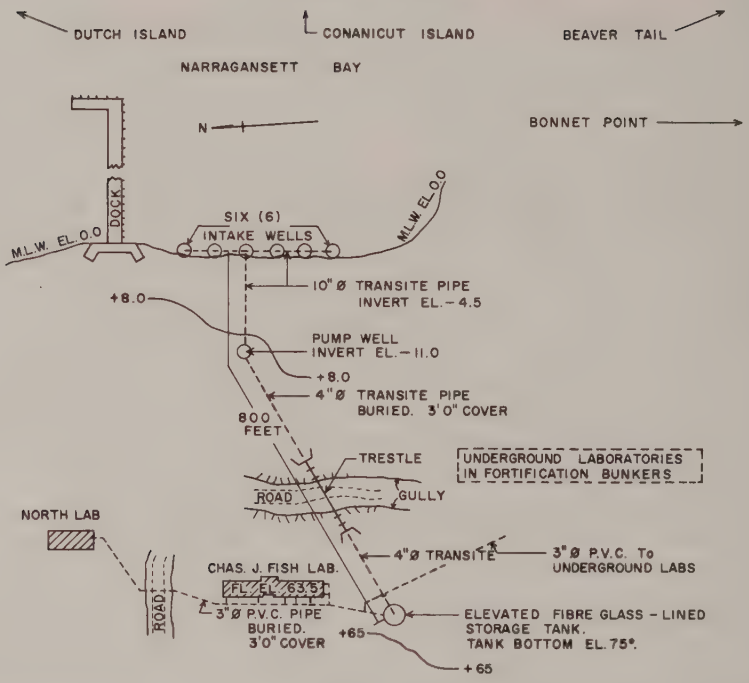

FIGURE 1.—Salt-water system at University of Rhode Island Graduate School of Oceanography, Saunderstown, R.I.

assembling of the entire intake well unit on shore and placement in the drained crater with a crane.

The pump well (fig. 2) accommodates one Flygt Bibo 4 submersible pump. A second pump is held in reserve for periodic rotation or quick replacement in case of emergency. This is facilitated by having each pump fully equipped with its discharge piping. Ever-tite aluminum rapid couplings and detachable electrical cables connect the pumps and receptacles, thus simplifying the task of making a pump change. The pump is of compact design weighing 170 pounds. It is 29 inches in height and 19 inches in external diameter.

The pipeline conveying water from the pump well to the elevated receiving tank is entirely self-draining without valleys or dips that would retain water between pumping periods. A check valve and a vacuum breaker in the line, just before entering the receiving tank, permit the line to empty itself entirely through the pump chamber within a few minutes after cessation of pumping. This self-draining feature of the line eliminates the necessity of insulating it against freezing. The line, 750 feet in length, is of 4-inch Transite pipe equipped with rubber ring couplings. Valves and checks are equipped with Buna-N seats and seals.

The receiving tank (fig. 3) is constructed of wood with a lining of 4-ply fiberglass. The supply and discharge pipes pass vertically through the bottom and are also of fiberglass. Two mercury float switches in the tank control starting and stopping of the water inflow, operation of the pump being electrically automatic.

The distribution pipes from the receiv-

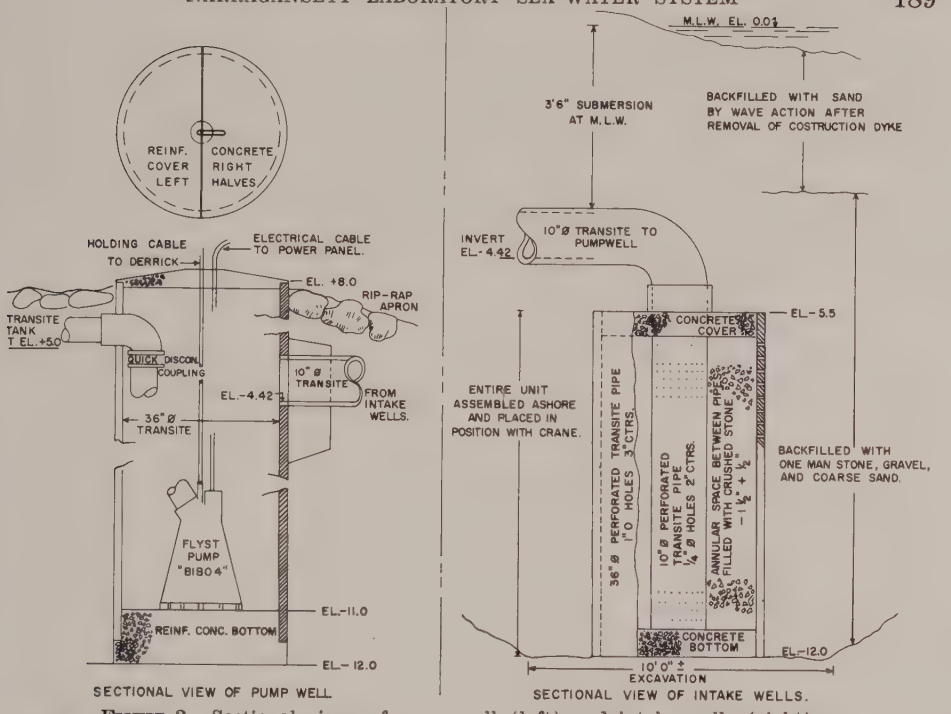
REINF. COVER LEFT
CONCRETE RIGHT HALVES
HOLDING CABLE TO DERRICK
ELECTRICAL CABLE TO POWER PANEL.
EL. +8.0
RIP-RAP APRON
TRANSITE TANK T EL. +5.0
QUICK DISCON. COUPLING
10" ø TRANSITE
FROM INTAKE WELLS.
EL.-4.42
36" ø TRANSITE
FLYST PUMP "BI804"
EL.-11.0
REINF. CONC. BOTTOM
EL.-12.0
SECTIONAL VIEW OF PUMP WELL
M.L.W. EL. 0.0'
3'6" SUBMERSION AT M.L.W.
BACKFILLED WITH SAND BY WAVE ACTION AFTER REMOVAL OF COSTRUCTION DYKE
INVERT EL.-4.42
10"ø TRANSITE TO PUMPWELL
CONCRETE COVER
EL.-5.5
ENTIRE UNIT ASSEMBLED ASHORE AND PLACED IN POSITION WITH CRANE.
36" ø PERFORATED TRANSITE PIPE 1"O HOLES 3" CTRS.
10" ø PERFORATED TRANSITE PIPE 1/4" ø HOLES 2" CTRS.
ANNULAR SPACE BETWEEN PIPES FILLED WITH CRUSHED STONE - 1 1/2" + 1/2"
BACKFILLED WITH ONE MAN STONE, GRAVEL, AND COARSE SAND.
CONCRETE BOTTOM
EL.-12.0
10'0" ± EXCAVATION
SECTIONAL VIEW OF INTAKE WELLS.

FIGURE 2.—Sectional views of pump well (left) and intake wells (right).

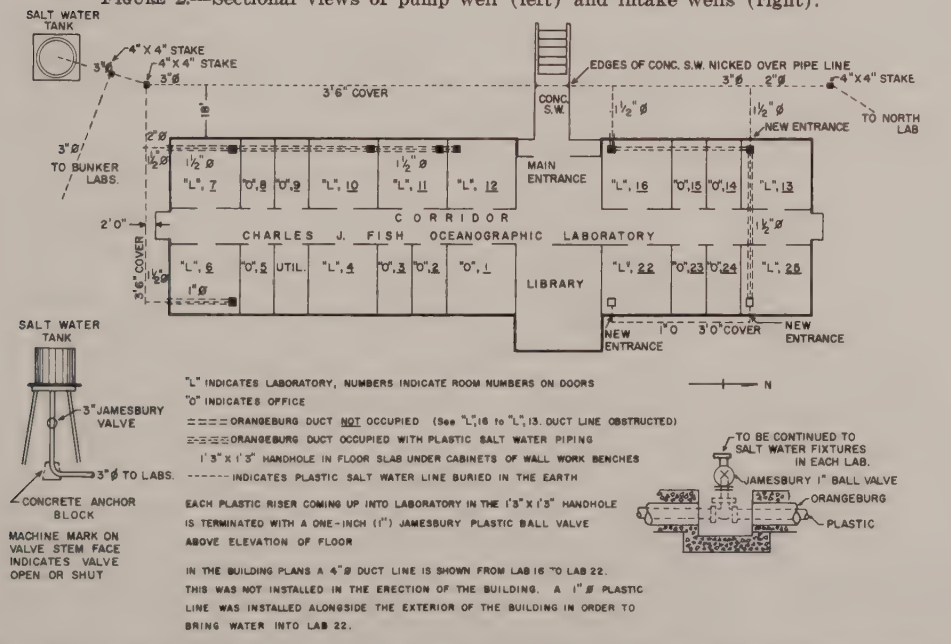
SALT WATER TANK
4" X 4" STAKE
4" X 4" STAKE
3" ø
3'6" COVER
EDGES OF CONC. S.W. NICKED OVER PIPE LINE
CONC. S.W.
1 1/2" ø
2" ø
4" X 4" STAKE
TO NORTH LAB
NEW ENTRANCE
3" ø TO BUNKER LABS.
2" ø
1 1/2" ø
"L", 7
"O",8
"O",9
"L", 10
"L", 11
"L", 12
MAIN ENTRANCE
"L", 16
"O",15
"O",14
"L", 13
C O R R I D O R
2'0"
CHARLES J. FISH OCEANOGRAPHIC LABORATORY
3'6" COVER
1 1/2" ø
"L", 6
"O",5
UTIL.
"L", 4
"O",3
"O",2
"O", 1
LIBRARY
"L", 22
"O",23
"O",24
"L", 26
1" ø
SALT WATER TANK
1'0
3'0" COVER
NEW ENTRANCE
NEW ENTRANCE
3" JAMESBURY VALVE
3" ø TO LABS.
CONCRETE ANCHOR BLOCK
MACHINE MARK ON VALVE STEM FACE INDICATES VALVE OPEN OR SHUT
"L" INDICATES LABORATORY, NUMBERS INDICATE ROOM NUMBERS ON DOORS
"O" INDICATES OFFICE
ORANGEBURG DUCT NOT OCCUPIED (See "L",16 to "L",13. DUCT LINE OBSTRUCTED)
ORANGEBURG DUCT OCCUPIED WITH PLASTIC SALT WATER PIPING
1'3" X 1'3" HANDHOLE IN FLOOR SLAB UNDER CABINETS OF WALL WORK BENCHES
INDICATES PLASTIC SALT WATER LINE BURIED IN THE EARTH
EACH PLASTIC RISER COMING UP INTO LABORATORY IN THE 1'3" X 1'3" HANDHOLE IS TERMINATED WITH A ONE-INCH (1") JAMESBURY PLASTIC BALL VALVE ABOVE ELEVATION OF FLOOR
IN THE BUILDING PLANS A 4" ø DUCT LINE IS SHOWN FROM LAB 16 TO LAB 22. THIS WAS NOT INSTALLED IN THE ERECTION OF THE BUILDING. A 1" ø PLASTIC LINE WAS INSTALLED ALONGSIDE THE EXTERIOR OF THE BUILDING IN ORDER TO BRING WATER INTO LAB 22.
N
TO BE CONTINUED TO SALT WATER FIXTURES IN EACH LAB.
JAMESBURY 1" BALL VALVE
ORANGEBURG
PLASTIC

FIGURE 3.—Diagrammatic sketch showing salt water distribution in Charles J. Fish Oceanographic Laboratory (not to scale).

ing tank to the working stations in the laboratories are of polyvinyl chloride. Each station is provided with Jamesbury plastic ball valves (fig. 3) and terminates with plastic faucets and swivel goosenecks. The plastic faucets are provided with plastic side valves for connection of flexible lines to laboratory aquaria.

Pumping against a head of 75 feet and through the 4-inch Transite line approximately 750 feet in length, the system is now delivering approximately 120 gallons per minute during the pumping periods. Added intake wells could be installed if an increased water supply should be required at some future time.

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